massDOT
Massachusetts Department of Transportation
Highway Division

JUNE 2024

Resilience Improvement Plan

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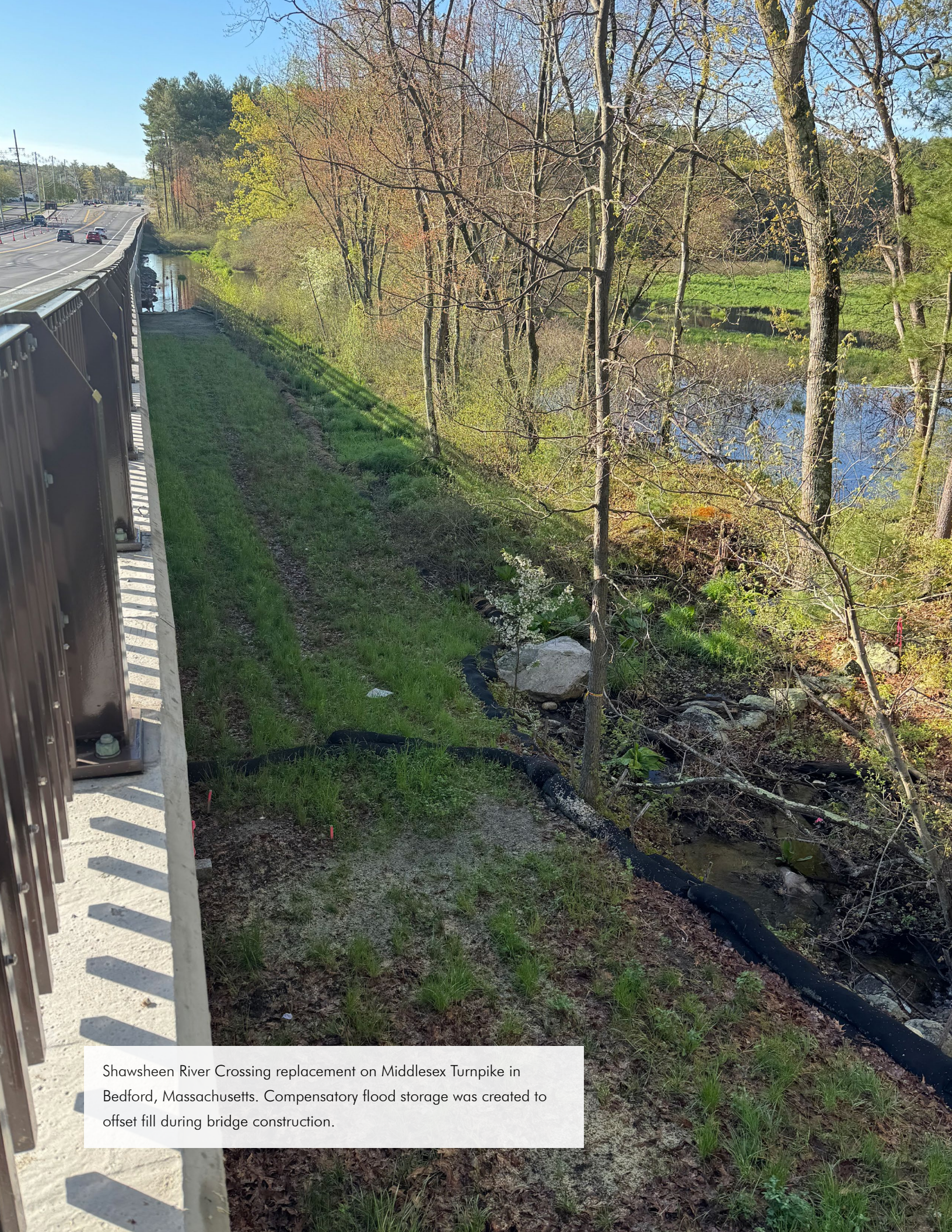

Shawsheen River Crossing replacement on Middlesex Turnpike in Bedford, Massachusetts. Compensatory flood storage was created to offset fill during bridge construction.

LIST OF ABBREVIATIONS

A&F	Executive Office for Administration and Finance
ARC	American Red Cross
BCA	Benefit Cost Analysis
BH-FRM	Boston Harbor-Flood Risk Model (predecessor to MC-FRM)
BIL	Bipartisan Infrastructure Law
BRIC	Building Resilient Infrastructure and Communities
CA/T	Central Artery/Tunnel System (portion of I-93 in Boston)
CCEPT	Cape Cod Emergency Traffic Plan
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
CMR	Code of Massachusetts Regulations
CIP	Capital Investment Plan
CTN	Critical Transportation Need
CZM	Massachusetts Coastal Zone Management
EEA	Executive Office of Energy and Environmental Affairs
EJ	Environmental Justice
ENF/EENF	Environmental Notification Form/Expanded Environmental Notification Form
ERC	Environmental Review Checklist
FEMA	Federal Emergency Management Agency
FFRMS	Federal Flood Risk Management System
FHWA	Federal Highway Administration
GeoDOT	MassDOT's GIS data portal
GHG	Greenhouse Gases
H&H	Hydrologic and Hydraulic

HEC	Hydraulic Engineering Circular (published by FHWA)
HMP	Hazard Mitigation Plan
HOC/BHOC	Highway Operations Center/Backup Highway Operations Center
IIJA	Infrastructure Investment and Jobs Act (also known as the BIL)
IPCS	Integrated Project Control System
JBCC	Joint Base Cape Cod
MA-ARNG	Massachusetts National Guard
MAESF-1	Massachusetts Emergency Support Function 1
MaPIT	MassDOT Highway Division's Project Intake Tool
MassDEP	Massachusetts Department of Environmental Protection
MassDOT	Massachusetts Department of Transportation
MassTRAC	An Act Relative to Massachusetts's Transportation Resources and Climate
MassWildlife	Massachusetts Division of Fisheries and Wildlife
MBTA	Massachusetts Bay Transportation Authority
MC-FRM	Massachusetts Coast Flood Risk Model
MEPA	Massachusetts Environmental Policy Act (Massachusetts General Laws , Chapter 30, Section 61-62)
MOVIT	Mapping our Vulnerable Infrastructure Tool
MPO	Metropolitan Planning Organization
MSP	Massachusetts State Police
MVP	Municipal Vulnerability Preparedness
NCHRP	National Cooperative Highway Research Program
NEPA	National Environmental Policy Act
NHS	National Highway System
OTP	Office of Transportation Planning (within MassDOT)
POMP	Programmatic Operations and Maintenance Plan
ProjectInfo	MassDOT Highway Division's On-Line Project Tracking System

PROTECT	Promoting Resilient Operations for Transformative, Efficient and Cost-Saving Transportation
RIP	Resilience Improvement Plan
RMAT	Resilient Massachusetts Action Team
SHMCAP	State Hazard Mitigation and Climate Adaptation Plan
SLR	Sea Level Rise
SLRTP	Statewide Long-Range Transportation Plan
SOGR	State of Good Repair
SSP	Specific Stream Power
STIP	State Transportation Improvement Program
TAMP	Transportation Asset Management Plan
TRB	Transportation Research Board
UAS	Unmanned Aerial Systems
UMass	University of Massachusetts
USACE	United States Army Corps of Engineers
U.S.C.	United States Code
USDOT	United States Department of Transportation
USGS	United States Geological Survey
WPA	Wetlands Protection Act (Massachusetts General Laws, Chapter 131, Section 40)

GLOSSARY & KEY TERMS

ADAPTATION: Adjustment in natural or human systems in anticipation of or response to a changing environment in a way that effectively uses beneficial opportunities or reduces negative effects.[1]

ADAPTIVE CAPACITY: The degree to which the system containing the asset (road, bridge, etc.) can adjust or mitigate the potential for damage or service interruption by the hazards.[2]

AT-RISK COASTAL INFRASTRUCTURE GRANTS: Through the PROTECT program, funds are eligible for strengthening, stabilizing, hardening, elevating, relocating or otherwise enhancing the resilience of highway and non-rail infrastructure, including bridges, roads, pedestrian walkways, bicycle lanes and associated infrastructure, such as culverts and tide gates to protect highways that are subject to, or face increased long-term future risks of, a weather event, natural disaster or changing conditions, including coastal flooding, coastal erosion, wave action, storm surge or sea level rise, in order to improve transportation and public safety and to reduce costs by avoiding larger future maintenance or rebuilding costs.[3]

BEYOND MOBILITY: Beyond Mobility is the Commonwealth's "Statewide Long Range Transportation Plan" (SLRTP) that will guide the work of MassDOT through 2050. Beyond Mobility serves as a blueprint for guiding transportation decision-making and investments throughout Massachusetts in a way that advances MassDOT's goals and maximizes the equity and resiliency of the transportation system.

BIPARTISAN INFRASTRUCTURE LAW (BIL): Signed into law in 2021, the BIL is a $1.2 trillion investment in our nation's infrastructure. It marks the largest investment in transit and electric vehicle infrastructure in United States history, the largest investment in bridges since the interstate system was built and in passenger rail since the creation of the National Railroad Passenger Corporation (Amtrak). The BIL includes provisions for the PROTECT program, including the Resilience Improvement Plan requirements.[4]

COMMUNITY RESILIENCE AND EVACUATION ROUTE GRANTS: Through the PROTECT program, there are funds eligible for projects that strengthen and protect evacuation routes essential for providing and supporting evacuations caused by emergency events.[5]

DISCRETIONARY or COMPETITIVE GRANTS: Grants that the USDOT awards through a competitive selection process to eligible applicants for select projects based on eligibility, evaluation criteria and program priorities, making it "discretionary." The PROTECT program offers two types of discretionary awards: planning grants and resilience improvement grants.

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1 "Highways in the Coastal Environment," Federal Highway Administration, Hydraulic Engineering Circular No. 25 (2020).
2 Ibid.
3 "H.R.3684 - Infrastructure Investment and Jobs Act," 117th Congress (2021).
4 "Fact Sheet: The Bipartisan Infrastructure Deal," White House Briefing Room (2021), accessed June 2024.
5 "H.R.3684 - Infrastructure Investment and Jobs Act," 117th Congress (2021).

ENVIRONMENTAL JUSTICE (EJ) POPULATION: In Massachusetts, an EJ population is defined as a neighborhood where one or more of the following criteria are true: the annual median household income is 65-percent or less of the statewide annual median household income, minorities make up 40-percent or more of the population, 25-percent or more of households identify as speaking English less than "very well," minorities comprise 25-percent or more of the population, and the annual median household income of the municipality in which the neighborhood is located does not exceed 150-percent of the statewide annual median household income.[6] Data to establish an EJ population designation are sourced from the U.S. Census Bureau, which provides demographic data by "Census block group."

EXPOSURE: The degree to which a transportation asset (road, bridge, etc.) experiences a hazard.[7]

EXTREME EVENT: Severe, rarely occurring event that usually causes damage, destruction or severe economic losses. Such events may include unseasonable weather, heavy precipitation, a storm surge, flooding, drought, windstorms, including hurricanes, tornadoes and associated storm surges, extreme heat, extreme cold, earthquakes and tsunamis.[8]

EMERGENCY EVENT: Per the PROTECT program, emergency event means a natural disaster or catastrophic failure resulting in an emergency declared by the Governor of the State in which the disaster or failure occurred or an emergency or disaster is declared by the President.[9]

FORMULA FUNDS: Also known as formula grants or Federal-aid funds, these guaranteed funds are distributed to States for a specific purpose, such as the PROTECT program; the amounts are determined by specific parameters set by Congress, such as State population.

FLUVIAL GEOMORPHOLOGY: The study of the interactions between the physical shapes of rivers, their water and sediment transport processes, and the landforms they create.[10]

NATURAL INFRASTRUCTURE: Infrastructure that uses, restores or emulates natural ecological processes and is created through the action of natural physical, geological, biological and chemical processes over time; is created by human design, engineering and construction to emulate or act in concert with natural processes; or involves the use of plants, soils and other natural features, including through the creation, restoration or preservation of vegetated areas using materials appropriate to the region to manage stormwater and runoff, to attenuate flooding and storm surges, and for other related purposes.[11]

NATURE-BASED SOLUTIONS: Options which mimic characteristics of natural features, but are created by human design, engineering and construction. They include a spectrum of natural and nature-based features that serve as alternatives to or enhancements of traditional shoreline stabilization and infrastructure protection techniques.[12]

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6 "2023 ResilientMass Plan," Massachusetts Executive Office of Energy and Environmental Affairs (2023), accessed May 2024.
7 "Highways in the Coastal Environment," Federal Highway Administration, Hydraulic Engineering Circular No. 25 (2020).
8 Ibid.
9 "H.R.3684 - Infrastructure Investment and Jobs Act," 117th Congress (2021).
10 "What is Fluvial Geomorphology (FGM)?," University of Massachusetts Amherst, Riversmart Communities, accessed May 2024.
11 "23 U.S. Code § 101 -Definitions and declaration of policy," Cornell Law School Legal Information Institute, accessed May 2024.
12 "Highways in the Coastal Environment," Federal Highway Administration, Hydraulic Engineering Circular No. 25 (2020).

NATIONAL ENVIRONMENTAL POLICY ACT (NEPA) AND COUNCIL ON ENVIRONMENTAL QUALITY (CEQ): NEPA was signed into law in 1970 and requires Federal agencies to assess the environmental effects of their proposed actions prior to making decisions.[13] NEPA established the CEQ to coordinate the Federal government's efforts to improve, preserve and protect America's public health and environment. The CEQ advises the President and develops policies on climate change, EJ, Federal sustainability, public lands, oceans and wildlife conservation, among other areas. As the agency responsible for implementing NEPA, CEQ also works to verify that environmental reviews for infrastructure projects and Federal actions are thorough, efficient and reflect the input of the public and local communities.[14]

PLANNING GRANTS: Through the PROTECT program, there are funds eligible for the purpose of developing a Resilience Improvement Plan; resilience planning, predesign, design or the development of data tools to simulate transportation disruption scenarios, including vulnerability assessments; technical capacity building to facilitate the ability of the eligible entity to assess the vulnerabilities of the surface transportation assets and community response strategies under current conditions and a range of potential future conditions; or evacuation planning and preparation.[15]

PROMOTING RESILIENT OPERATIONS FOR TRANSFORMATIVE, EFFICIENT AND COST-SAVING TRANSPORTATION (PROTECT) PROGRAM: Under Title 23 USC Section 176, the PROTECT program provides funding to verify surface transportation resilience to natural hazards, including climate change, sea level rise, flooding, extreme weather events and other natural disasters through support of planning activities, resilience improvements, community resilience and evacuation routes, and at-risk coastal infrastructure.[16]

RESILIENCE: Per the BIL, the term "resilience," with respect to a project, means "a project with the ability to anticipate, prepare for or adapt to conditions or withstand, respond to or recover rapidly from disruption, including the ability to (A)(i) to resist hazards or withstand impacts from weather events and natural disasters; or (A)(ii) to reduce the magnitude or duration of impacts of a disruptive weather event or natural disaster on a project; and (B) to have the absorptive capacity, adaptive capacity and recoverability to decrease project vulnerability to weather events or other natural disasters."[17]

RESILIENCE IMPROVEMENT GRANTS: Through the PROTECT program, there are funds eligible for State DOTs to improve the ability of an existing surface transportation asset to withstand one or more elements of a weather event or natural disaster, or to increase the resilience of surface transportation infrastructure from the impacts of changing conditions, such as sea level rise, flooding, wildfires, extreme weather events and other natural disasters.[18]

RESILIENCE IMPROVEMENT PLAN (RIP): The RIP is an optional component of the PROTECT program that can reduce the State and local cost-share for discretionary grant funded projects if the plan contents satisfy the requirements outlined in Title 23 U.S.C. 176(e)(2).

RESILIENTMASS: The Commonwealth of Massachusetts' initiative for building statewide capacity for climate change adaptation and resilience.

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13 "NEPA," United States Environmental Protection Agency (2023), accessed May 2024.
14 "Council On Environmental Quality," whitehouse.gov, accessed May 2024.
15 "H.R.3684 - Infrastructure Investment and Jobs Act," 117th Congress (2021).
16 "Bipartisan Infrastructure Law Fact Sheet," Federal Highway Administration (2022), accessed May 2024.
17 "H.R.3684 - Infrastructure Investment and Jobs Act," 117th Congress (2021).
18 "Bipartisan Infrastructure Law Fact Sheet," Federal Highway Administration (2022), accessed May 2024.

SCOUR: Erosion of streambed or bank material due to flowing water; often considered as being localized around piers and abutments of bridges.[19]

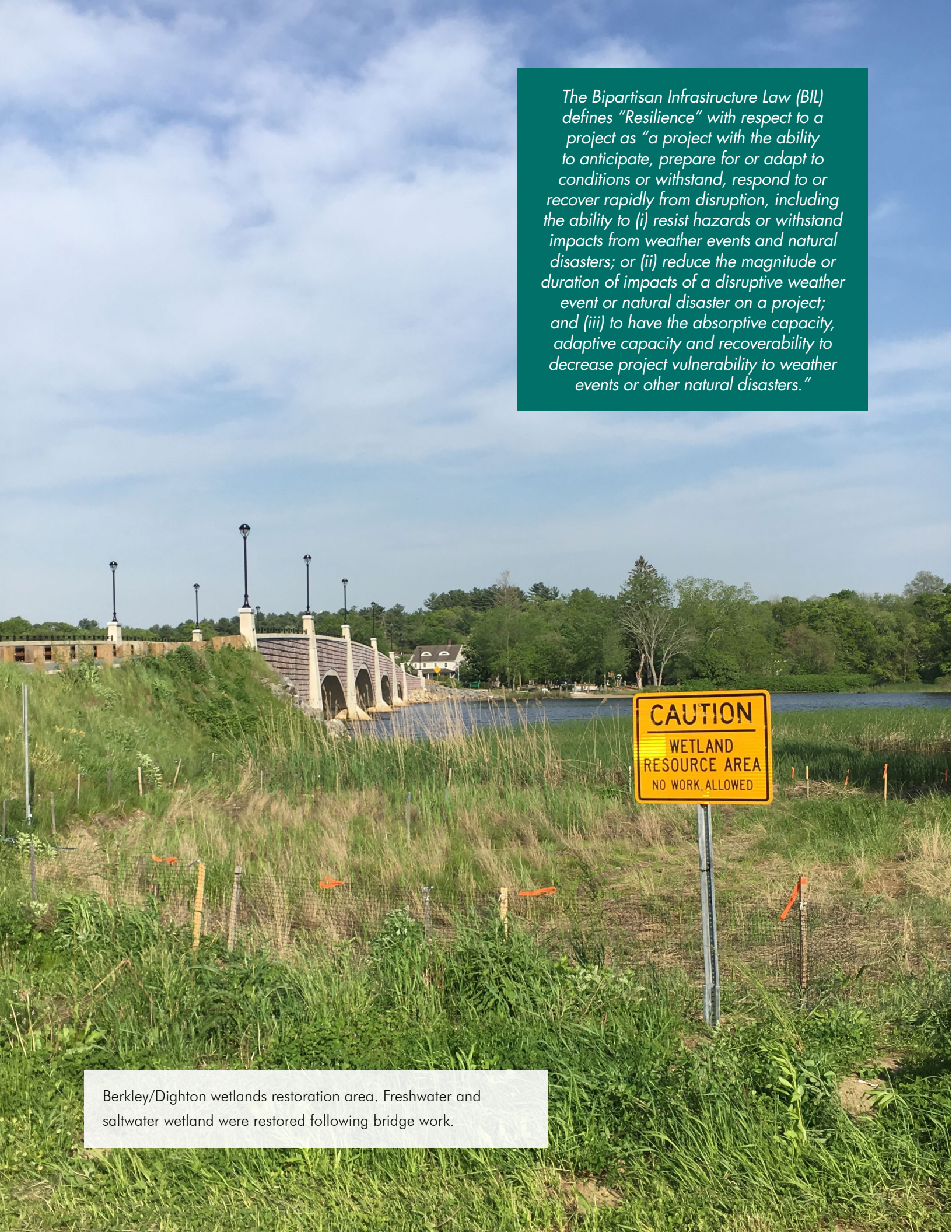
SURFACE TRANSPORTATION ASSETS: Facilities, equipment or systems used to provide transportation services by a public transportation agency, a railroad carrier, an owner or operator of an entity offering scheduled, fixed-route transportation services by over-the-road bus or a bus terminal, or other services as determined by USDOT.[20]

SENSITIVITY: The degree to which an asset (road, bridge, etc.) is damaged or service is interrupted by the hazards.[21]

VULNERABILITY: The extent to which a transportation asset or system is susceptible to sustaining damage from hazards during extreme events. Vulnerability is a function of the extent to which an asset or system is exposed to damaging forces, its sensitivity to those forces and its adaptive capacity.[22]

19 "23 CFR § 650.305 - Definitions," Cornell Law School Legal Information Institute, accessed June 2024.
20 "6 U.S. Code § 124h-1 – Threat information sharing," Cornell Law School Legal Information Institute, accessed May 2024.
21 "Highways in the Coastal Environment," Federal Highway Administration, Hydraulic Engineering Circular No. 25 (2020).
22 Ibid.

The Bipartisan Infrastructure Law (BIL) defines "Resilience" with respect to a project as "a project with the ability to anticipate, prepare for or adapt to conditions or withstand, respond to or recover rapidly from disruption, including the ability to (i) resist hazards or withstand impacts from weather events and natural disasters; or (ii) reduce the magnitude or duration of impacts of a disruptive weather event or natural disaster on a project; and (iii) to have the absorptive capacity, adaptive capacity and recoverability to decrease project vulnerability to weather events or other natural disasters."



Berkley/Dighton wetlands restoration area. Freshwater and saltwater wetland were restored following bridge work.

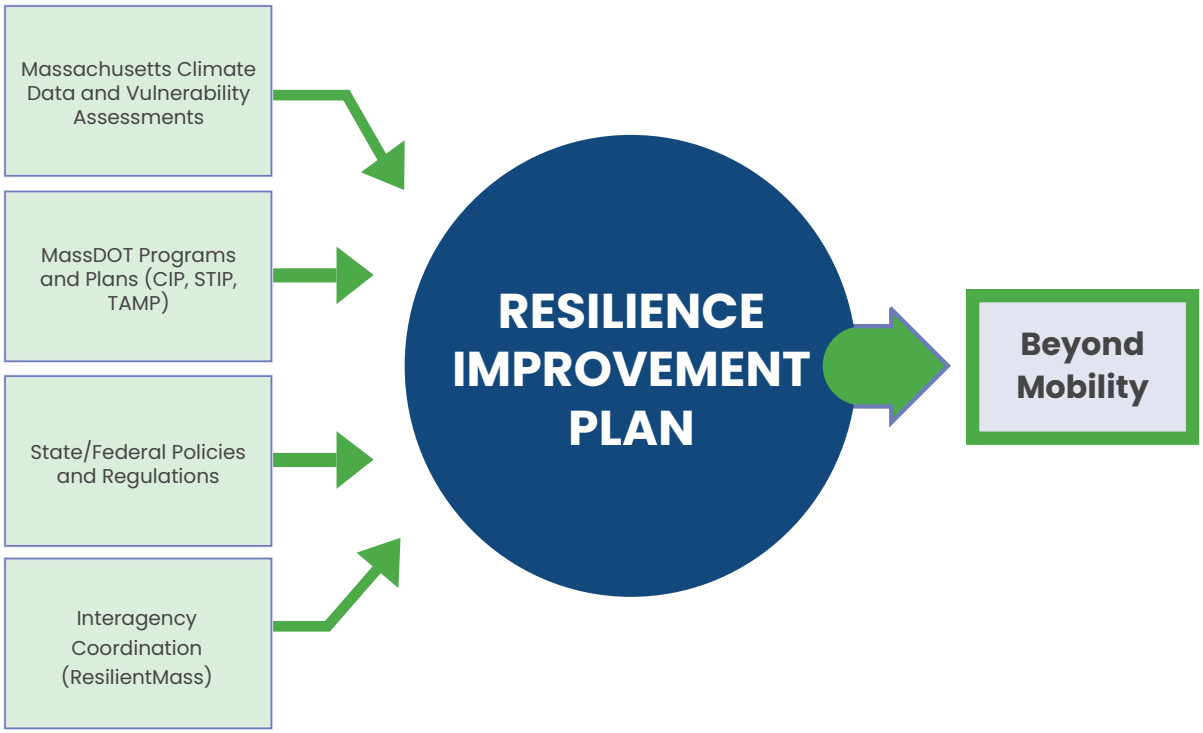
SECTION 1: INTRODUCTION

The Massachusetts Department of Transportation (MassDOT) Highway Division presents its Resilience Improvement Plan (RIP) to demonstrate a systematic approach to surface transportation system resilience and how it informs immediate and long-range planning activities and investments.

The RIP summarizes the policies, plans and assessments that contribute to MassDOT Highway Division's understanding of surface transportation asset and system risk and build resilience. It provides a roadmap for continuing to increase resilience through planning and investments.

This plan is informed by State and Federal legislation and executive orders (**Section 2**), risk-based assessments of current and future climate vulnerabilities (**Section 3**), and MassDOT's progress developing resilience-focused plans and processes; integrating resilience considerations into project initiation, development and design processes; maintaining a state of good repair (SOGR); responding to extreme weather events; and coordinating with local, regional, State and Federal partners. MassDOT's systemic approach to resilience (**Section 4**) supports transportation investment decisions (**Section 5**) with the goal of increasing resilience and measuring performance (**Section 6**).

The RIP is integrated into Beyond Mobility, MassDOT's Statewide Long Range Transportation Plan (SLRTP) that captures a planning period through 2050, and is also included as an appendix to the SLRTP.


Massachusetts Climate Data and Vulnerability Assessments
MassDOT Programs and Plans (CIP, STIP, TAMP)
State/Federal Policies and Regulations
Interagency Coordination (ResilientMass)
RESILIENCE IMPROVEMENT PLAN
Beyond Mobility

This RIP is specific to the Highway Division of MassDOT, which is responsible for more than 9,500 roadway miles, more than 5,000 bridges, culverts and tunnels, as well as pedestrian, transit and bicycle facilities. The Highway Division also oversees the design and construction of Federally funded municipal projects. Surface transportation projects considered in this plan are assets that MassDOT Highway Division is responsible for maintaining and operating, including:

- Highways
- Pavement
- Curbs and guardrails
- Bridges and Culverts
- Drainage Structures
- Pedestrian, Transit and Bicycle Facilities
- Tunnels
- Maintenance Facilities
- Ancillary Structures[1]
- Ventilation Buildings

The MassDOT Highway Division is responsible for the various stages of project development, including project scoping, 25- to 100-percent design, construction, and maintenance and operations. This RIP details MassDOT Highway Division's systematic approach to improving resilience at each of the various project development stages and discusses how extreme weather and climate change are incorporated into immediate and long-range planning activities. MassDOT Highway Division's approach to resiliency has five components, each of which includes actions that have been completed, actions that are ongoing or in-progress, and future actions that are proposed to further advance resiliency work in the years ahead.

PLAN
Prepare for changing conditions and extreme events through vulnerability assessments and identify criteria to evaluate transportation asset vulnerabilities.
INFORM
Coordinate resilience approach and actions with ResilientMass, municipalities, municipal planning organizations and the public.
IMPROVE
Incorporate resilience measures into projects and initiate resiliency-focused projects.
MASSDOT HIGHWAY DIVISION
Resiliency Approach
RESPOND
Build and maintain capabilities to respond to and quickly recover from disruptions from extreme weather and changing conditions.
MAINTAIN
Reduce disruption from extreme weather and changing conditions to existing assets over their service life through maintenance, planning and coordination.

[1] Ancillary Structures include traffic signals, lighting, signage, cameras, dams, etc.

The current and future weather events, natural disasters and impacts to transportation systems discussed within the RIP align with the natural hazards defined in the 2022 Massachusetts Climate Assessment and 2023 ResilientMass Plan.[2] The underlying climate data and projections used in the RIP are included as **Appendix 1** and specific vulnerabilities of transportation infrastructure to these hazards are described in detail in **Section 3.**

2023 ResilientMass Plan Natural Hazards

MassDOT Highway Division Priorities

- **Flooding from Precipitation**
- **Coastal Flooding and Sea Level Rise (SLR)**
- **Average and Extreme Temperatures**
- **Coastal Erosion**
- **Changes in Groundwater/ Groundwater Rise**
- **Earthquakes**
- **Landslide and Mudflows**
- **Hurricane and Tropical Cyclones**
- **Severe winter storms/ Nor'easters**

Additional Natural Hazards

- **Tornadoes**
- **Tsunami**
- **Other Severe Weather**
- **Wildfire**
- **Invasive Species**
- **Drought (including impacts to groundwater)**

[2] "Resilient Mass Plan," Table 5.1 – 1, Massachusetts Executive Office of Energy and Environmental Affairs (2023)

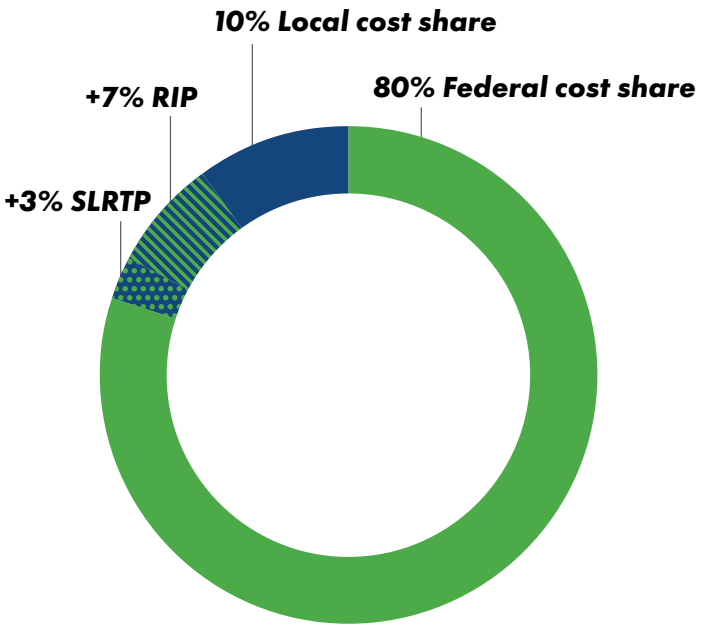
Consistency of RIP Content with Federal Requirements

MassDOT Highway Division's RIP has been developed in accordance with Federal requirements per the provisions of Promoting Resilient Operations for Transformative, Efficient and Cost-Saving Transportation (PROTECT) program in the Bipartisan Infrastructure Law (BIL) [23 U.S.C. 176 § 11405].

The BIL authorized new Federal investments in infrastructure, including roads, bridges, mass transit, water infrastructure, broadband and resilience. The law amends several existing Federal infrastructure programs to include as eligible projects that reduce greenhouse gas emissions and increase resilience, including protective features and natural infrastructure. It further amends certain programs to prioritize the flow of benefits to disadvantaged communities. The law created new regulations for States to consider resiliency and extreme weather in asset management plans [23 U.S.C. 119(e)(4)(D) § 11105].

The BIL established the PROTECT program to help make surface transportation more resilient to natural hazards through formula funding and discretionary grants for eligible entities and activities, including planning grants [23 U.S.C. 176(c)(2) and 176(d)(3) § 11405], resilience improvement grants [23 U.S.C. 176(d)(4)(A) § 11405], community resilience and evacuation routes grants [23 U.S.C. 176(d)(4)(B) § 11405], and at-risk costal infrastructure grants [23 U.S.C. 176(d)(4)(C) § 11405]. **At least $106.5 million in PROTECT formula funding is anticipated to be apportioned to MassDOT during fiscal years 2022-2026.**

In addition to the formula funds, $1.4 billion in discretionary grants are available for highway projects eligible under Title 23 U.S.C.; public transportation facilities or services eligible under chapter 53 of Title 49 U.S.C.; or port facilities, including facilities that connect ports with other modes of transportation, improve the efficiency of evacuations and disaster relief, or aid transportation [23 U.S.C. 176(c)(3)(B) § 11405].



The Federal cost share is generally up to 80-percent, but the non-Federal share may be reduced by up to 10-percent if the State develops a RIP in accordance with 23 U.S.C. 176(e) and prioritizes the project on that plan (7-percent), and if the plan is incorporated into the SLRTP under 23 U.S.C. 135 (3-percent) [23 U.S.C. 176 (e)(1)(B) § 11405]. The RIP is appended to Beyond Mobility, the SLRTP and Table 1.1 outlines where the requirements for 23 U.S.C. 176(e) are met within this document to receive maximum Federal cost share for MassDOT projects identified in **Appendix 3.**[3]

[3] The list of prioritized resilience investments will be updated as new projects are identified and approved through the MassDOT Project Review Committee process.

Table 1.1: Consistency with Federal Requirements

REGULATION	DESCRIPTION	RIP SECTION
23 USC 176(e)(2)(A)	Immediate and long-range planning activities and investments	4, 5, Appendix 2, Appendix 3
23 USC 176(e)(2)(B)	Systemic approach to surface transportation system resilience	2, 3, 4, 5
23 USC 176(e)(2)(B)	Consistency with and complementary of the State and local mitigation plans	3, 4
23 USC 176(e)(2)(C)	Risk-based assessment of vulnerabilities of transportation assets and systems to current and future weather events and natural disasters	3
23 USC 176(e)(2)(D)(iii)	Resilience improvement policies, including strategies, that will inform the transportation investment decisions	2, 4, 5
23 USC 176(e)(2)(D)(v)	Use science and data and indicate the source of data and methodologies	3, Appendix 1
23 USC 176(e)(2)(E)(i)	How the plan will improve the ability of the State to respond promptly to the impacts of weather events and natural disasters and be prepared for changing conditions (ex. sea level rise)	4, 5
23 USC 176(e)(2)(E)(ii)	Codes, standards and regulatory framework, if any, adopted and enforced to provide resilience improvements	2
23 USC 176(e)(2)(E)(iv)	Assessment of other community assets, including buildings and housing, emergency management assets, and energy, water and communication infrastructure	3
23 USC 176(e)(2)(E)(iv)(I)	Priority project list	Appendix 3
23 USC 176(e)(2)(E)(iv)(II)	Description of how PROTECT funds would be invested and matched	5
23 USC 176(e)(2)(E)(v)	Long-term planning period	5

Roadway flooding at the Shawsheen River Crossing on the Middlesex Turnpike in Bedford, Massachusetts.

SECTION 2: STATE AND FEDERAL BACKGROUND

There are several State and Federal executive orders and laws that influence MassDOT's resilience improvements.

Table 2.1: Massachusetts Executive Orders and Legislation

STATE RULE	OVERVIEW
Massachusetts Executive Order No. 569: Establishing an Integrated Climate Change Strategy for the Commonwealth (2016)	Required an integrated State Hazard Mitigation and Climate Adaptation Plan (SHMCAP). It also established Climate Change Coordinators from each Executive Office to form the Resilient Massachusetts Action Team (RMAT), which has responsibility to implement the SHMCAP. MassDOT Highway Division is a member of the RMAT and has participated in several administration-wide resilience initiatives, including the development of the 2018 SHMCAP and the five-year SHMCAP update: 2023 ResilientMass Plan.
Massachusetts Executive Order No. 579: Establishing the Commission on the Future of Transportation in the Commonwealth (2018)	Established a commission tasked with laying out potential developments in the transportation field between 2020 and 2040, and to advise the Governor and Lieutenant Governor on how to confirm that transportation planning, forecasting, operations and investments for this period can best account for future conditions, including disruptive technologies, climate change, land use and demographic trends. The commission delivered a report with a sub-recommendation to complete vulnerability assessments of all publicly-owned or funded transportation infrastructure to inform capital planning and disseminate resiliency-oriented design standards for transportation infrastructure.
Massachusetts Environmental Protection Agency (MEPA) Interim Protocol on Climate Change Adaptation and Resiliency (2021)	Established a new section entitled "Climate Change Adaptation and Resiliency Section" to the Environmental Notification Form (ENF) and requires new projects filing with the MEPA office to submit the output report generated from the RMAT Climate Resilience Design Standards Tool. The protocol complies with Executive Order 569 and builds on the recommendations of the 2018 SHMCAP. The interim protocol is anticipated to be superseded by a formal Climate Change Adaptation and Resiliency Policy in the future.
An Act Creating a Next-Generation Roadmap for Massachusetts Climate Policy (2021)	Filed to establish statewide emissions limit and sector-specific sub-limits that are updated every five years. The legislation also set requirements to verify State agencies, including MassDOT, consider defined environmental justice (EJ) principles in making any policy, determination or taking any other action related to a project review, or in undertaking any project that is likely to affect EJ populations.
An Act Relative to Massachusetts' Transportation Resources and Climate (MassTRAC) (2022)	Filed to confirm the Commonwealth could fully leverage the funding authorization provided under the BIL. The Legislature passed the $11.3 billion transportation and infrastructure bond bill. MassTRAC provides MassDOT and the Massachusetts Bay Transportation Authority (MBTA) the necessary authorization to take advantage of the Federal highway and transit funding under BIL.
Massachusetts Executive Order No. 604: Establishing the Office of Climate Innovation and Resilience (2023)	Established the Office of Climate Innovation and Resilience and Chief Climate Officer to advance the Commonwealth's climate innovation, mitigation, adaptation and resilience policies. The Office tracks the success of executive department agencies and offices in achieving progress toward the Commonwealth's climate goals. MassDOT is a member of the Office's workgroup to identify benefits from climate-related investments and connect those to Federal funding opportunities. MassDOT is also a collaborator with other State agencies in advancing resilience recommendations through the PROTECT program.[4]

[4] "No. 604: Establishing the Office of Climate Innovation and Resilience Within the Office of the Governor," Commonwealth of Massachusetts Executive Orders (2023), accessed May 2024

ResilientMass

ResilientMass is the Commonwealth of Massachusetts' initiative for building statewide capacity for climate change adaptation and resilience.

The ResilientMass Plan is Massachusetts' SHMCAP, first developed in 2018 and updated in 2023. It aims to verify the Commonwealth is prepared to withstand, rapidly recover from, adapt to and mitigate natural hazard events. MassDOT Highway Division is one of 29 State agencies included in the Commonwealth's Plan.

ResilientMass Plan
2023 MASSACHUSETTS STATE HAZARD MITIGATION AND CLIMATE ADAPTATION PLAN
EXECUTIVE SUMMARY | September 2023
2023

Led by the Executive Office of Energy and Environmental Affairs (EEA) and the Massachusetts Emergency Management Agency (MEMA), the RMAT is an inter-agency working group comprised of representatives from each Secretariat, called Climate Change Coordinators, who are supported by agency staff, stakeholders and subject matter experts. The RMAT is tasked with monitoring and tracking the ResilientMass Plan implementation process, making recommendations to and supporting agencies on plan updates, and facilitating coordination across State government and with stakeholders. Through ResilientMass, MassDOT coordinates with other State agencies and the Governor's office to incorporate climate resilience throughout the Commonwealth.

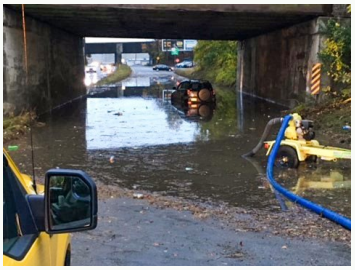
127
state agency actions*
95 actions to increase coastal resilience
110 actions to reduce flooding in Massachusetts
75 actions to improve resilience of state assets
30 actions to increase economic resilience
80 actions to address extreme temperatures
35 actions to protect and enhance biodiversity
1 ResilientMass Plan

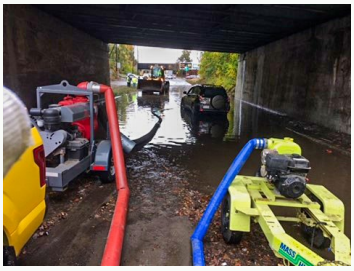
Source: ResilientMass Plan Summary

MassDOT Highway Division's involvement in statewide coordination on resilience and assessment of vulnerabilities has proven results. The 2018 SHMCAP and 2023 ResilientMass Plan identified actions for MassDOT Highway Division to improve MassDOT's ability to respond promptly to the impacts of weather events and natural disasters and be prepared for changing conditions. Actions from both plans are noted in **Section 4.**

Table 2.2: Federal Executive Orders and Legislation

FEDERAL RULE	OVERVIEW
Executive Order 13690 (reinstated through Executive Order 14030 in 2021)	The Federal Flood Risk Management Standard (FFRMS) encourages Federal agencies to consider and manage current and future flood risks by requiring agencies to prepare for and protect Federally funded buildings and projects. FFRMS requires agencies to select one of three approaches to establish the flood elevation and corresponding flood hazard area used for project siting, design and construction. On October 2, 2023, the Federal Emergency Management Agency (FEMA) published revisions to its floodplain management regulations at Title 44 Part 9 of the Code of Federal Regulations (CFR): Floodplain Management and Protection of Wetlands in the Federal Register. The revisions propose to fully implement the FFRMS and incorporate natural features or nature-based solutions into project design that reduce local flood risk and increase resilience against flooding. *MassDOT's Highway Division's Bridge Section is currently using the methods outlined in the FFRMS as described in* **Section 4**. *MassDOT also regularly considers fluvial geomorphology in the project development process for bridge, culverts and roads along rivers and streams. This provides an opportunity to integrate nature-based solutions into projects, improve and/or restore natural flow regimes, minimize sediment and wood transport, and reconnect floodplains.*
Promoting Resilient Operations for Transformative, Efficient and Cost-Saving Transportation (PROTECT) in the BIL (2021)	The PROTECT program allows eligible agencies to make their transportation infrastructure more resilient to natural disasters and delivers $7.3 billion in formula funds apportioned to State DOTs during 2022 through 2026. Of the annual PROTECT formula funds, a State: • may not use more than 40-percent of funds for construction of new capacity and/or more than 10-percent of funds for development phase activities • must set aside at least 2-percent of funds for specified types of resilience-related planning activities, such as developing a resilience improvement plan; resilience planning, predesign or design; technical capacity-building; or evacuation planning and preparation. *MassDOT's investment plans account for the PROTECT program formula funds, as described in* **Section 5.** *In addition to the guaranteed formula funds, MassDOT was awarded a resilience improvement grant for "Flood Relief on Route 20/Grafton St (Route 122) Interchange to Flint Pond" in Worcester, Massachusetts to upgrade drainage infrastructure. The improved drainage structures will reduce road closures during storm events, enhance safety and improve reliability for drivers along this critical route.*
White House Council on Environmental Quality (CEQ) Interim Guidance on Consideration of Greenhouse Gas (GHG) Emissions and Climate Change (2023)	This guidance is intended to assist Federal agencies in their consideration of the effects of GHG emissions and climate change when evaluating proposed major Federal actions in accordance with the National Environmental Policy Act (NEPA). In addition to interim guidance on reducing GHG emissions and assessing carbon counts as part of alternatives, there is interim guidance on "Considering the Effects of Climate Change on a Proposed Action." *While still interim, MassDOT considers GHG emissions for its major projects through the NEPA process.*





Grafton Street, Worcester, Massachusetts, on 10/22/2016. The region experienced more than 3 inches of precipitation in 3 hours, resulting in stormwater flooding.

Culvert on New Salem Road over an unnamed brook in Petersham, Massachusetts. Culvert is frequently blocked by debris buildup.

SECTION 3: RISK-BASED ASSESSMENT OF VULNERABILITIES

MassDOT has conducted numerous risk-based assessments of transportation asset and system vulnerabilities to current and future weather events and natural disasters. MassDOT partners with other State agencies through RMAT, and coordinates with local and regional partners to assess transportation asset and system risk at the State and local level. A summary of key risk-based assessments informing MassDOT Highway Division's resilience approach is shown in Table 3.1. Details on the climate projection data used in these assessments are included in **Appendix 1.**

Table 3.1: Summary of risk-based vulnerability assessments completed and hazards assessed

HAZARDS ASSESSED	2015 MassDOT – FHWA Pilot Project: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery	2018 Statewide Hazard Mitigation and Climate Adaptation Plan	2018 MassDOT - Deerfield Watershed Stream Crossing Resilience Pilot Project	2019 MassDOT - FHWA Pilot Project: Asset Management, Extreme Weather, and Proxy Indicators	2022 Massachusetts Climate Change Assessment	2023 ResilientMass Plan	2024 MassDOT - Flood Risk Assessment
Flooding from Precipitation		X	X	X	X	X	X
Coastal Flooding and Sea Level Rise	X	X			X	X	
Average and Extreme Temperatures		X			X	X	
Coastal Erosion		X			X	X	
Changes in Groundwater/ Groundwater Rise					X	X	
Earthquakes		X			X	X	
Landslide and Mudflows		X			X	X	
Hurricane and Tropical Cyclones	X	X			X	X	
Severe winter storms/ Nor'easters	X	X			X	X	

MassDOT – FHWA Pilot Project: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery (Completed 2015)

MassDOT sought to better understand the vulnerability of the I-93 Central Artery/Tunnel (CA/T) in Boston, Massachusetts to sea level rise (SLR) and extreme storm events. I-93 is a major north-south transportation corridor that traverses Boston through a network of more than 160 lane-miles, with more than half of those lane-miles located within tunnels, six interchanges and 200 bridges.

A state-of-the-art hydrodynamic flood model, the Boston Harbor Flood Risk Model (BH-FRM), was developed to support the vulnerability assessment. The project team combined the BH-FRM with agency-driven knowledge and priorities to assess vulnerabilities and develop adaptation strategies for this valuable component of transportation infrastructure. MassDOT worked closely with project stakeholders and a technical advisory team to assess the impacts of climate change on the I-93 CA/T system. Coastal flood maps illustrating the annual exceedance probabilities of flooding in Boston Harbor, with 0.62-foot SLR (2030 projections) and 3.2-foot SLR (2070 projections), are shown in Figure 3.1.

The study presented the following conclusions:

- **Present data/near term risk:** It is likely that relatively self-supporting temporary barriers will be sufficient to manage flooding for CA/T structures on or above the ground surface up to at least 2030. The study showed that flood depths with SLR around these structures did not exceed the critical depth threshold of two feet at the flood exceedance probability of 1-percent with the exception of the few watertight doors.
- **Late century risk:** By 2070 or 2100 depending on SLR, approximately 30 CA/T structures on or above the ground surface structures will need protection with flood walls under a local adaptation strategy. In addition, under a local adaptation strategy, seven portals will require flood gates and that number will continue to grow to more than 50 by late century.
- **Estimated costs for adaptation:** The team estimated that total materials and installation costs for protecting non-tunnel structures through 2100 would be nearly $47 million, and the materials and installation costs for watertight gates at tunnel portals would be approximately $27 million under 2013 flood conditions, with an additional $19 million needed for protection through 2030. The team estimated that additional costs to protect the tunnels through the late 21st century would be nearly $150 million.

The BH-FRM identified flood risks in the Greater Boston Harbor region beyond MassDOT Highway systems and informed the Commonwealth's first fully-integrated hazard mitigation and climate adaptation plan, described in the following subsection.

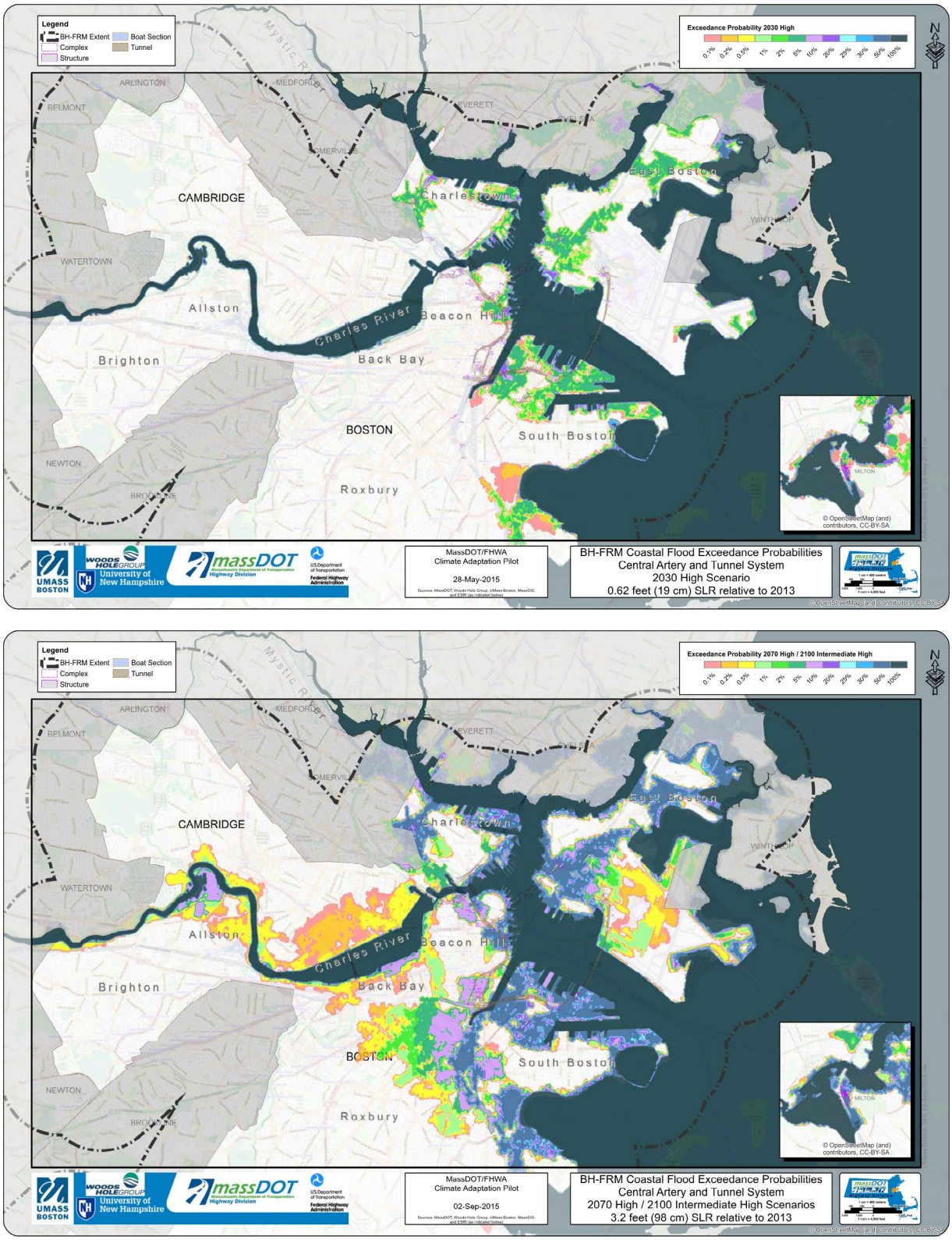


Figure 3.1: Coastal Flood Exceedance Maps from the 2015 FHWA Pilot Project with top showing projected inundation by 2030 (0.62 feet of SLR) and bottom showing projected inundation by 2070 (3.2 feet of SLR). *(Source 2015 FHWA Pilot Project.)*

Massachusetts State Hazard Mitigation and Climate Action Plan (Completed 2018)

The 2018 Massachusetts State Hazard Mitigation and Climate Adaptation Plan (2018 SHMCAP) was the Commonwealth's first fully-integrated statewide hazard mitigation and climate adaptation plan to account for projected changes in precipitation, temperature, SLR and extreme weather events. This plan is the predecessor to the 2023 ResilientMass Plan, described later in this section.

MassDOT participated in the development of the 2018 SHMCAP, which was led by the Massachusetts Emergency Management Agency (MEMA) and the Executive Office of Energy and Environmental Affairs (EEA). The plan identified risks and vulnerabilities associated with natural disasters and climate change, including the following impacts pertinent to MassDOT Highway Division:

Heavy precipitation events may lead to ponding on roadways and/or damage to roads and bridges, which may dramatically affect commerce and public health and safety if alternative routes are not available.

Landslides may block roadway access and/or weaken soils that make roads and bridges hazardous for use. Landslides can also cause bridge abutment or embankment failure. This may isolate neighborhoods, cause roadway closures, increase traffic delays and/or result in economic losses.

Coastal flooding may damage roadways and crossings, particularly those that are hydraulically undersized or tidally restricted and/or flood roadways. Over time, more frequent overtopping may be expected during storms and non-storm high-tide events. This may isolate neighborhoods, cause roadway closures, impact emergency services, increase traffic delays and/or result in economic losses.

Extreme heat may reduce material stability, particularly pavement that softens and expands when exposed to extreme heat over long periods of time. This can cause buckling, rutting, potholes, place additional stress on bridge joints, and/or lead to failures that increase the frequency of repairs and replacements. Enclosure-encased equipment, such as traffic control devices, are vulnerable to equipment failure from extreme internal temperatures. Associated power outages from extreme heat may affect electrical power ancillary assets for highway operations, such as electronic signing. Increased heat can affect the viability of vegetation in rights-of-way. Extreme temperatures also discourage active modes of transportation, such as bicycling and walking, and impact transportation workers and maintenance schedules.

The 2018 SHMCAP developed long-term strategies for protecting people and property from natural hazard events and climate change impacts. Actions developed by MassDOT Highway Division are integrated into the MassDOT Highway Division Resiliency Approach in **Section 4.**

MassDOT Deerfield Watershed Stream Crossing Resilience Pilot Project (Completed 2018)

MassDOT partnered with the University of Massachusetts (UMass) Amherst in 2014 to conduct a Deerfield River Watershed Stream Crossing Resilience Pilot Project (Deerfield Pilot) to assess the vulnerability of road-stream crossings to climate change. The pilot study included approximately 1,000 road-stream crossings in the Deerfield River watershed of Massachusetts, which straddles the border between northwestern Massachusetts and southern Vermont. The watershed experienced multiple culvert failures, damage to bridges, and associated transportation disruptions as a result of runoff volume, bank erosion, undermining and landslides caused by Tropical Storm Irene. The goal of the Deerfield Pilot was to:

- Develop methodologies for assessing structural, geomorphic and hydraulic risk of failure for road-stream crossings and the associated disruption of emergency medical services.
- Use these new methodologies, along with existing methodologies for assessing ecological disruption, to assess road-stream crossings in the Massachusetts portion of the Deerfield River watershed.
- Incorporate climate change into hydraulic analyses using down-scaled climate models to predict future flows and hydraulic risk of failure for road-stream crossings.

The vulnerability of road-stream crossings to climate change was determined by combining a relative measure of risk of failure due to structural, geomorphic and hydraulic risk; predicted climatic conditions; and the criticality of each crossing to the transportation network, as determined by a model based on recorded emergency vehicle routes. Hydraulic and geomorphic risk of failure was based on relative risk rather than absolute risk due to the uncertainties in the hydrologic models, climate models and hydraulic capacity estimates. A comparison of the hydraulic risk scores for multiple models under current and mid-century climate conditions are shown in Figure 3.2.

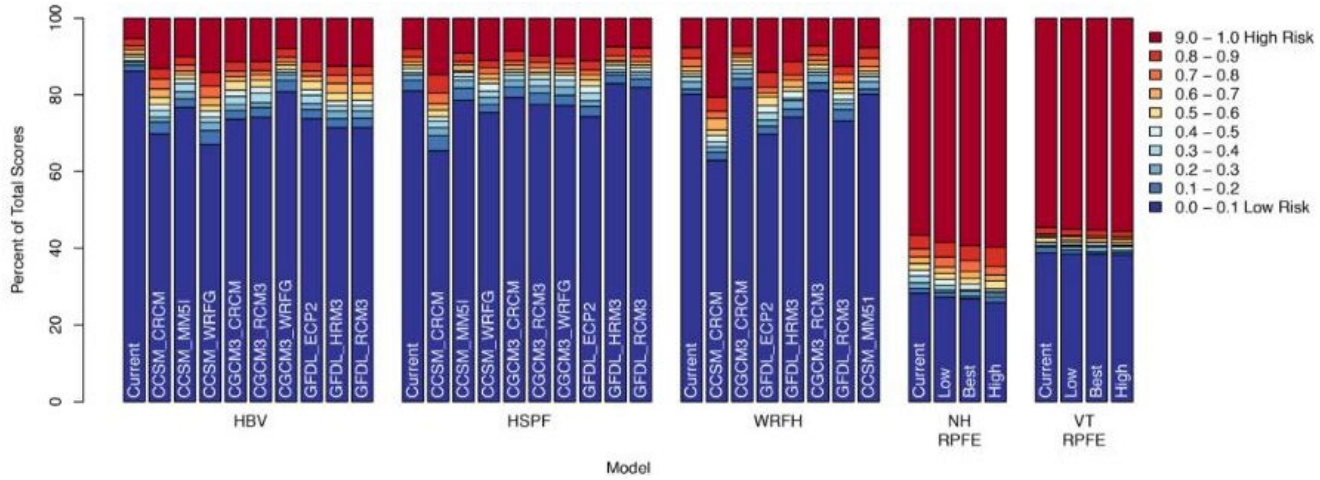


Figure 3.2: Graphs illustrating hydraulic risk of failure (on a scale of zero to one) for crossings within the Deerfield Watershed that were estimated using five different hydraulic models and current and projected climate conditions. *(Source Deerfield Pilot.)*[5]

[5] The grouping of columns is based on hydraulic models: Hydrologiska Byrans Vattenbalansavdelning (HBV), Hydrologic Simulation Program Fortran (HSPF) and WRF-Hydro (WRFH) are physical stream flow models, while Regional Peak Flow Equations (RPFE) for New Hampshire and Vermont are statistical stream flow models that include average precipitation as a variable. The bars represent climate simulations modeled.

An additional analysis incorporating the impacts of ecological disruption and the potential ecological value of road-stream crossing upgrades was added to create a final relative crossing prioritization score. The results were made available to the public in a webtool located at sce.ecosheds.org and published in a report titled "Deerfield River Watershed Pilot: A Proposed Method for Assessing the Vulnerability of Road-Stream Crossings to Climate Change." The report described the methods used; discussed sources of uncertainty, including lack of stream gauge data, high level of variability across different hydrological model outputs and climate models, and lack of confidence in using data from past events to predict future frequency of storms; and shared lessons learned.

The Deerfield Pilot report included a number of recommendations for future work, including potential future research topics, testing an updated version of the prioritization scheme in other watersheds and extending risk of failure assessments across Massachusetts. The variables that influence vulnerability identified in the Deerfield Pilot were used for the MassDOT - FHWA Pilot Project: Asset Management, Extreme Weather and Proxy Indicators Pilot Project, which is described in the following subsection.

The report recommended adopting the Massachusetts River and Stream Crossings Standards (stream crossing standards), originally developed to avoid creating barriers to aquatic organism passage and maintain aquatic connectivity, rather than trying to establish design standards for crossings based on changing storm recurrence rates. The project also recommended exploring fluvial geomorphic principles to reduce risk of failure for bridge and culvert design.

West Oxbow Road bridge replacement over Wilder Brook in Charlemont, Massachusetts. The bridge was designed to stream crossing standards. Riprap scour protection was covered with natural streambed material and a grade control weir was installed to protect the stream against incision. Wildlife benches were installed along the face of the bridge abutments.

MassDOT - FHWA Pilot Project: Asset Management, Extreme Weather and Proxy Indicators Pilot Project (Completed 2019)

This pilot used proxy variables estimated at the State scale to perform an initial flood resilience screen for 2,787 MassDOT bridges and 1,171 culverts. The assessment included use of downscaled precipitation projections, which estimated a 5- to 10-percent mean annual precipitation increase over the next 50 years. MassDOT was one of six State DOTs that partnered with FHWA to integrate resilience considerations into their asset management processes. Vulnerability was assessed based on estimated structure geomorphic compatibility, for example percent bankfull width (%Wbankfull) and potential channel erosion vulnerability, such as specific stream power (SSP) and bed resistance, as shown in Figure 3.3. The projected increase in size and frequency of future floods as a result of climate change is likely to increase potential channel erosion and structure vulnerability; larger flows and stream power increases erosion potential; and crossing structures will need to pass more water, sediment and large debris.

		Estimated Structure Geomorphic Compatibility		
		Low	Moderate	High
		($\%_{Wbankfull} < 50$)		($\%_{Wbankfull} \geq 100$)
Potential Channel Erosion Vulnerability (SSP and Bed Resistance)	High	H	H	M
	Moderate	H	M	L
	Low	M	L	L

Figure 3.3: Matrix used to estimate structure vulnerability. *(Source 2019 FHWA Pilot Project.)*

The assessment found that:

- Vulnerable structures are geographically spread across the Commonwealth.
- Most culverts (86-percent) currently have moderate to high estimated vulnerability and low geomorphic compatibility. Culverts with high estimated vulnerability are projected to increase by approximately 41-percent by 2070.
- Most bridges (92-percent) currently have low to moderate estimated vulnerability. Bridges with high estimated vulnerability are projected to increase by approximately 6-percent by 2070.
- Culverts are of particular concern since less is known about location, size, condition and geomorphic compatibility as compared to bridges.
- Potential channel erosion vulnerability is predicted to increase with climate change. The percentage of miles of stream channel with moderate to high channel erosion vulnerability is projected to increase from 23- to 25-percent by 2070.

As recommended by study findings, the vulnerability data were incorporated into GeoDOT, MassDOT's geographic information system (GIS) database portal. Culvert and bridge vulnerability considerations have been incorporated into the MassDOT Highway Division's Project Intake Tool (MaPIT) project scoring process.

Massachusetts Climate Change Assessment (Completed 2022)

The Massachusetts Climate Change Assessment (2022 MA Climate Assessment), developed in coordination with RMAT, evaluates the impacts of climate change to the Commonwealth, including relevant details about climatic trends for each of the four projection eras (2030, 2050, 2070 and 2090), and how those projections vary across Massachusetts. The 2022 MA Climate Assessment identifies and prioritizes the impacts from climate stressors, such as temperature, precipitation and SLR, and climate hazards, including extreme heat, flooding and droughts, across five sectors: human, infrastructure, natural environment, governance and economy.

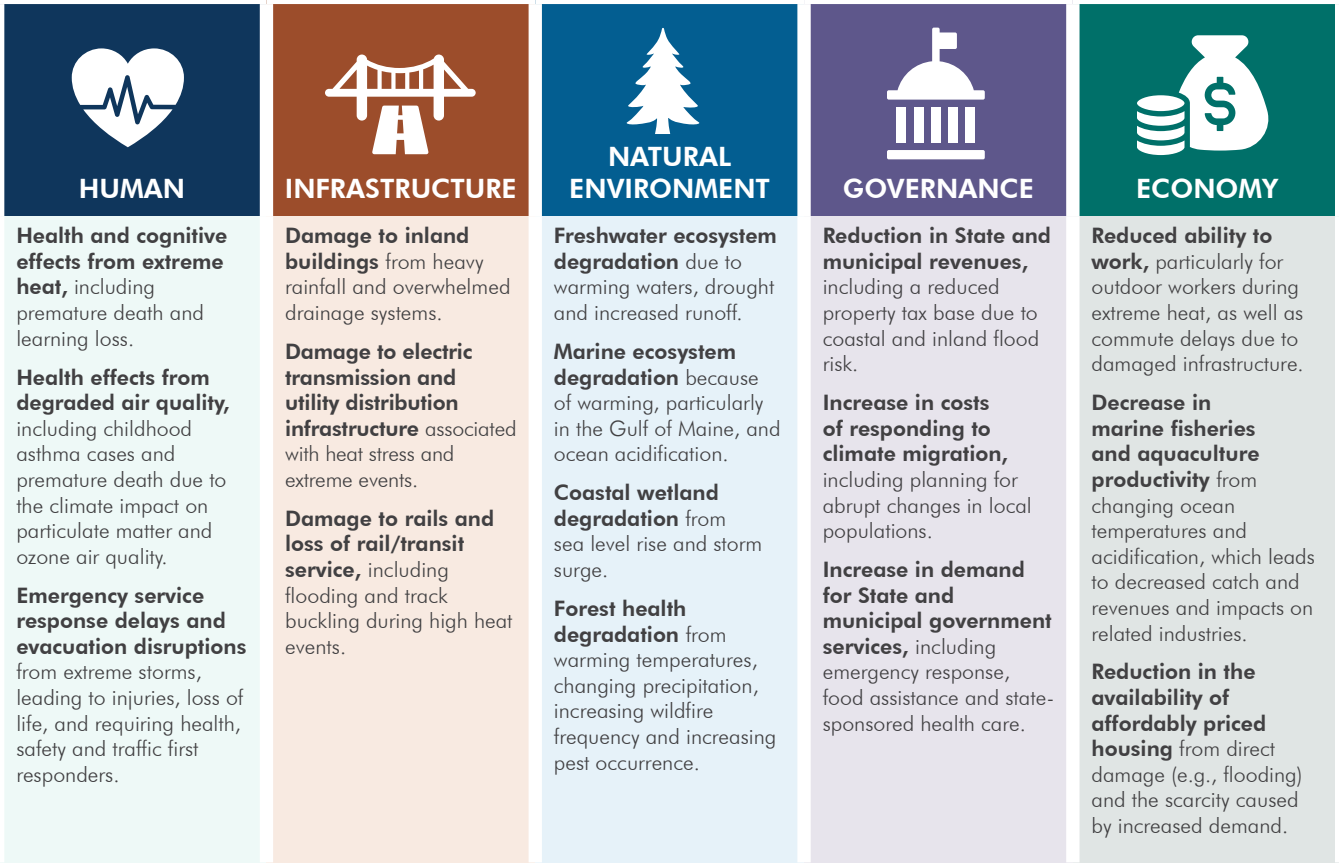

HUMAN
Health and cognitive effects from extreme heat, including premature death and learning loss.
Health effects from degraded air quality, including childhood asthma cases and premature death due to the climate impact on particulate matter and ozone air quality.
Emergency service response delays and evacuation disruptions from extreme storms, leading to injuries, loss of life, and requiring health, safety and traffic first responders.
INFRASTRUCTURE
Damage to inland buildings from heavy rainfall and overwhelmed drainage systems.
Damage to electric transmission and utility distribution infrastructure associated with heat stress and extreme events.
Damage to rails and loss of rail/transit service, including flooding and track buckling during high heat events.
NATURAL ENVIRONMENT
Freshwater ecosystem degradation due to warming waters, drought and increased runoff.
Marine ecosystem degradation because of warming, particularly in the Gulf of Maine, and ocean acidification.
Coastal wetland degradation from sea level rise and storm surge.
Forest health degradation from warming temperatures, changing precipitation, increasing wildfire frequency and increasing pest occurrence.
GOVERNANCE
Reduction in State and municipal revenues, including a reduced property tax base due to coastal and inland flood risk.
Increase in costs of responding to climate migration, including planning for abrupt changes in local populations.
Increase in demand for State and municipal government services, including emergency response, food assistance and state-sponsored health care.
ECONOMY
Reduced ability to work, particularly for outdoor workers during extreme heat, as well as commute delays due to damaged infrastructure.
Decrease in marine fisheries and aquaculture productivity from changing ocean temperatures and acidification, which leads to decreased catch and revenues and impacts on related industries.
Reduction in the availability of affordably priced housing from direct damage (e.g., flooding) and the scarcity caused by increased demand.

Figure 3.4: Most urgent priority impacts identified in the 2022 MA Climate Assessment across five sectors. *(Source 2022 MA Climate Assessment.)*

For each impact, the 2022 MA Climate Assessment answers:

- How big of a climate effect will this have?
- Will populations living in EJ areas be disproportionally affected?
- Are we currently doing enough to adapt to this impact?

The urgent impacts identified through the 2022 MA Climate Assessment that pertain to MassDOT Highway Division include:

- **Emergency Service Response Delays and Evacuation Disruptions (Impact: Most Urgent):** Extreme storms cause delays in response time for emergency and law enforcement services, potentially leading to loss of life. Coastal and inland events may flood evacuation routes, trapping residents and leading to increased loss of life and injuries. The impact accounts for potential emergency response delays and economic losses from traffic delays. Projected traffic delays measured in vehicle-hours as a result of a 2070 100-year coastal flood event are shown in Figure 3.5.

  There is high potential for traffic delays in the large urban areas of Suffolk and Middlesex Counties in the Boston Harbor region. This represents a disproportionate exposure of impact to EJ block groups.

- **Damage to Rails and Loss of Rail/Transit Service (Impact: Most Urgent):** While not MassDOT Highway Division assets, rapid transit systems are disproportionately relied on by EJ populations and road usage increases during rail outages and service delays, which affects highway traffic volumes.

- **Damage to Roads and Loss of Road Service (Impact: Urgent):** Climate impacts road surface conditions and the structural integrity of bridges and culverts at road crossings. Extreme temperatures, wetter weather and flooding reduces pavement performance and increases the need for repair and maintenance. The anticipated increase in maintenance costs over baseline rise to $45 million a year by 2050 and $140 million a year by 2090. Figure 3.6 illustrates the total increase in cost-per-lane-mile expected by the end of century at a quarter degree grid scale across the Commonwealth; road costs increase more significantly in parts of western Massachusetts and in the Cape, Islands and South Coast region than in the mid- and north-eastern parts of the State. Changes to culvert and bridge design standards and integration of nature-based flood mitigation strategies are possible adaptation actions to reduce the magnitude of these identified impacts.

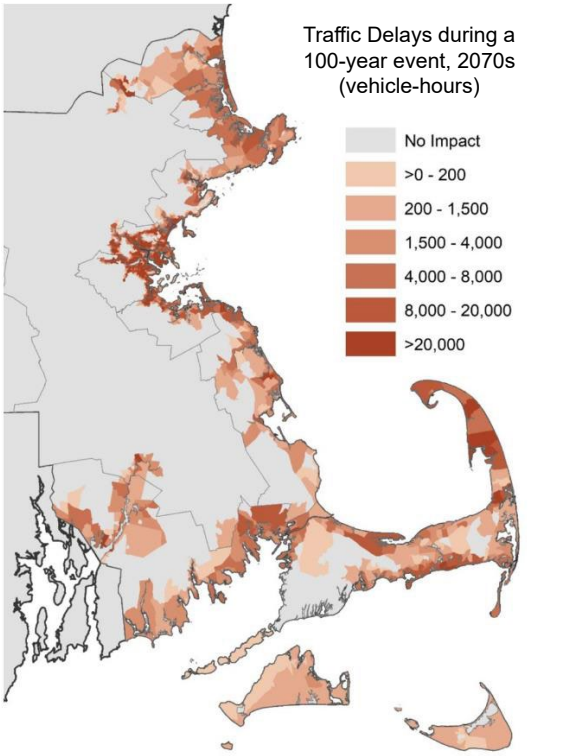


Figure 3.5: Traffic delays impacting emergency response by block group for a 100-year return period coastal flood (one-percent chance of occurring annually) by 2070. *(Source 2022 MA Climate Assessment.)*

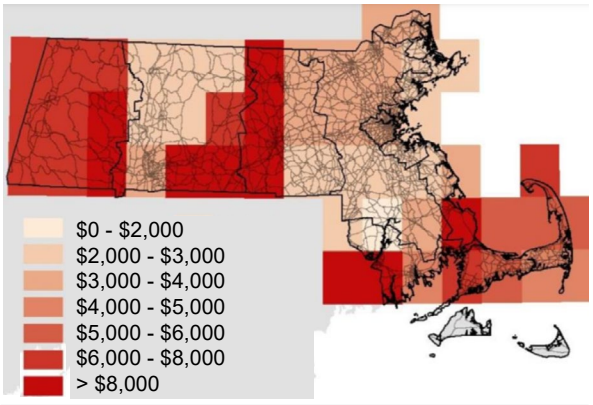


Figure 3.6: Total increase in road maintenance costs ($/lane-mile) from current to 2090 time period. *(Source 2022 MA Climate Assessment.)*

ResilientMass Plan (State Hazard Mitigation and Climate Action Plan) (Completed 2023)

The ResilientMass Plan is the five-year update to the 2018 SHMCAP. The plan aims to increase Massachusetts' capacity for addressing natural and other hazards and climate impacts through preparation, mitigation, adaptation and risk reduction. The following goals of the plan were developed through a collaborative process involving the interagency RMAT and local, regional and community partners:

- Collaboration, communication, funding and engagement
- Science-based and informed decision-making
- Resilient State assets and services
- Implementation of adaptation actions for communities and ecosystems
- Climate mitigation
- Resilient and equitable infrastructure, ecosystems and communities

The ResilientMass Plan integrates the findings from the 2022 MA Climate Assessment with additional analysis on all current hazards that may impact the Commonwealth, as well as future risks that will increase the likelihood, frequency and duration of hazards. For example, changes in precipitation are expected to vary geographically and seasonally as shown in Figure 3.7. The ResilientMass Plan's expanded risk assessment uses the same hazards and five sectors as the 2022 MA Climate Assessment (see Figure 3.4 in previous subsection). The plan analyzes the exposure and vulnerability from each hazard and identifies specific areas or assets of concern for each sector. These data help inform MassDOT Highway Division's systematic approach to resiliency outlined in **Section 4.**

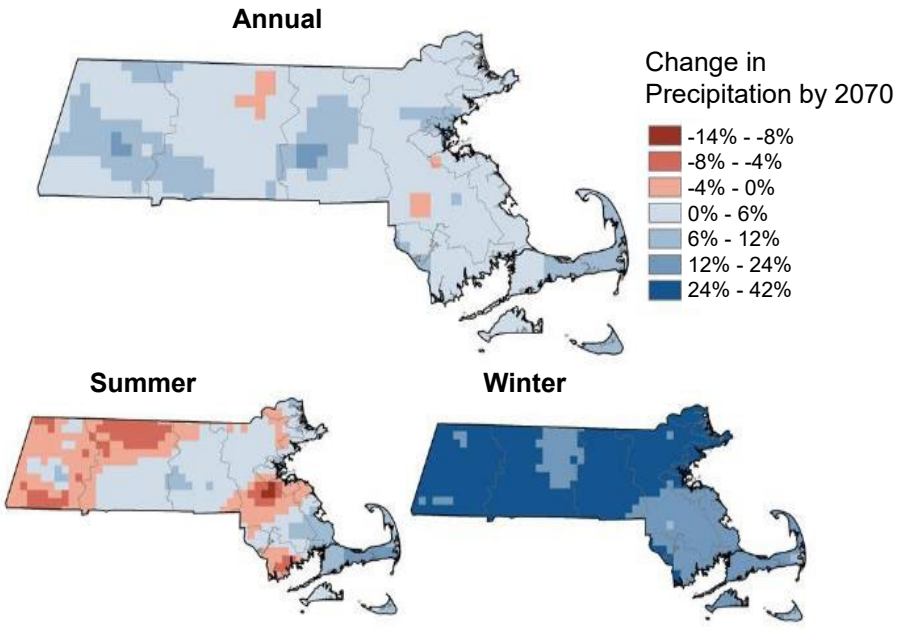


Figure 3.7: Predicted change in annual, summer and winter season precipitation between current and 2070 climate conditions. *(Source 2023 ResilientMass Plan.)*

The transportation infrastructure vulnerabilities identified in the ResilientMass Plan are summarized by natural hazard:

Flooding from Precipitation: Aging culverts and bridges are vulnerable to riverine flooding impacts, such as bridge scour, overtopping, culvert blowout and road embankment destabilization. Figure 3.7 illustrates the projected percent changes in precipitation across the Commonwealth between current and 2070 climate conditions. Up to 25-percent of bridges in New England may be vulnerable to bridge support scour caused by high river flow events. Flooding can result in dangerous road conditions, damage to roadways and even washed-out roads.

Coastal Flooding and Sea Level Rise (SLR): Many state-operated coastal roads are likely to be at risk from coastal flooding due to projected SLR. Existing development puts added pressure on coastal floodplains and exacerbates coastal flood risk in highly developed areas.

Average and Extreme Temperatures: Roadways and railways are constructed with thermally sensitive materials, which expand when hot and shrink when cold. Buckling tracks and damage from more frequent freeze-thaw cycles pose an increased risk to transportation infrastructure.

Coastal Erosion: Infrastructure near the shoreline, including coastal roadways, bridges and airports, will be vulnerable to coastal erosion.

Groundwater Rise: Roads will experience repeated damage from increased soil saturation from rising groundwater. SLR affects groundwater in coastal areas.

Earthquake: Bridges, underground subway and highway tunnels in areas susceptible to liquefaction are particularly vulnerable.

Landslide and Mudflows: These are typically a secondary hazard to earthquakes and extreme precipitation events. Landslide and mudflow risk is higher in the western portion of the Commonwealth. Steep slopes, loose soils and excessive soil moisture reduce slope stability, which impacts roadway embankments.

Hurricanes and Tropical Cyclones: Coastal areas are most vulnerable. Tropical storms lose strength once they move inland; however, significant hurricane impacts have occurred in western Massachusetts in recent years. The strong winds, coastal surge and heavy rainfall generated from these storms impact low-lying and linear infrastructure and utility networks, including roads, bridges, trails, and air and marine travel.

Severe Winter Storms: Coastal areas are more vulnerable to impacts from nor'easters due to the strong winds/wave action and storm surge. Ice storms and heavy snow can result in delays or damages to roadways and public transit. Additional impacts to energy and communications infrastructure can also disrupt transportation systems.

Other Severe Weather: Roads, bridges, cargo and passenger rail, and transit may be vulnerable to disruptions from falling trees, landslides, downed power and communication lines, flooding or debris.

Tornadoes: Public safety facilities and equipment, as well as roads, bridges and rail systems, were identified as among the types of infrastructure that could be vulnerable to tornadoes.

Wildfires: Roads, bridges and rail systems in wildfire risk zones were identified as vulnerable, as they may become blocked due to fire and debris.

MassDOT - Flood Risk Assessment (completed for District One in 2024)

Referred to as the Statewide Transportation Asset Inland Flooding Vulnerability Assessment in the 2018 SHMCAP, MassDOT Office of Transportation Planning (OTP) conducted a flood risk assessment to understand weather events and future flood-related threats to a range of critical transportation infrastructure in MassDOT Highway's District One in 2024. District One is the highway district located furthest west in the Commonwealth as shown in Figure 3.8. There are approximately 3,300 road miles in District One, with approximately 78-percent categorized as rural roads.

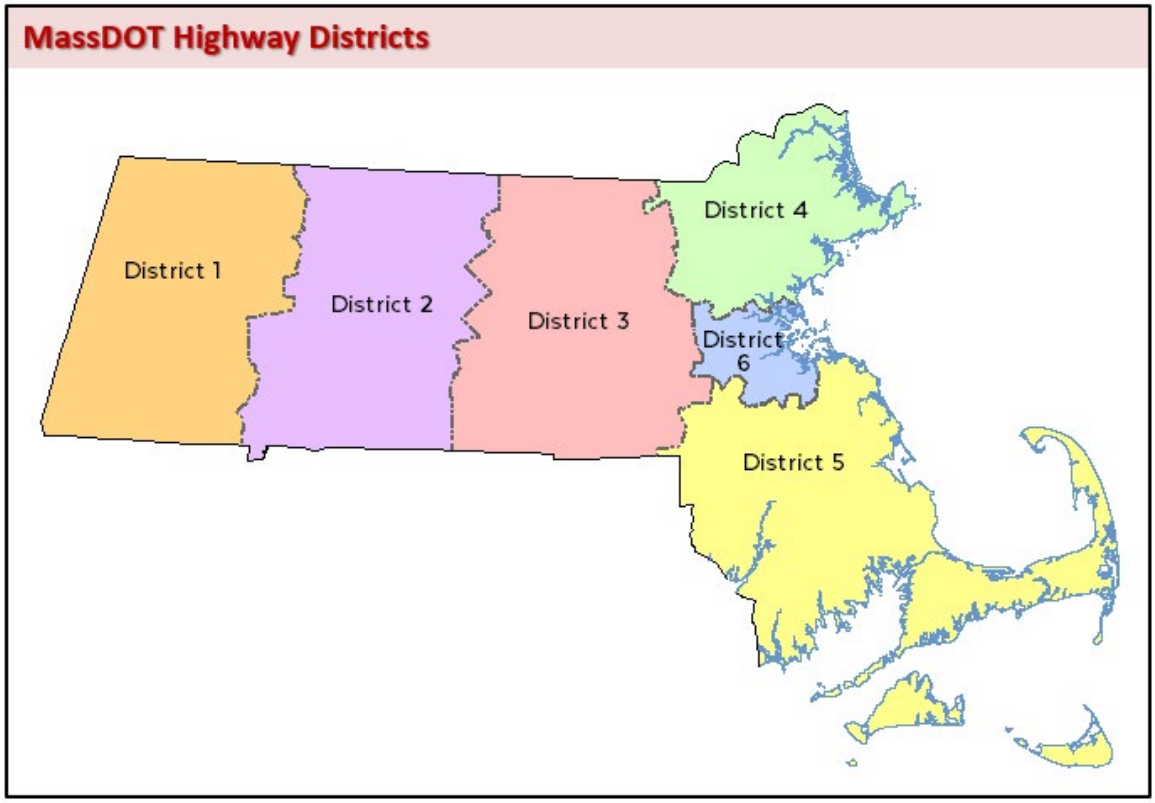


Figure 3.8: Map illustrating the six districts of MassDOT Highway Division. District One (1) is the furthest west. *(Source Mass.gov.)*

This study focused on National Highway System (NHS) roadways, bridges and large culverts, as well as rail and airport infrastructure, and the risk of riverine flooding over the coming decades. The analysis included a probabilistic simulation of future outcomes that modeled stream flows, flooding and erosion, asset damage and user impacts. In addition to identifying the transportation assets exposed to damage under various time horizons, return periods and climate scenarios, the work estimated the expected costs to MassDOT and motorists, pedestrians, bicyclists and taxpayers in the Commonwealth if no resiliency actions are taken.

MassDOT OTP is preparing summaries of these results for relevant internal groups. Once available, the results will be incorporated into subsequent revisions to the RIP.

Route 2/7 over a tributary to Hemlock Brook in Williamstown, Massachusetts. An undersized culvert that regularly became blocked by sediment was replaced with an 8x8 box culvert to improve hydraulics and sediment transport.

Beaver Brook Road over Beaver Brook in Westford, Massachusetts. Two twin corrugated steel culverts were regularly clogging and were replaced by a bridge. The bridge improved hydraulics and significantly reduced clogging potential from beaver debris. Additionally, the new bridge increased the openness ratio and ambient lighting under the structure, improving the passage for a rare turtle species native to the area.

SECTION 4: RESILIENCY APPROACH

Extreme weather and climate change are included as part of immediate and long-term planning activities for MassDOT Highway Division. MassDOT Highway Division's approach to resiliency has five components, which build upon State and Federal regulations, past accomplishments and actions, vulnerability assessments and interagency coordination. MassDOT is preparing for a changing climate and the RIP identifies needs to establish criteria and best practices based on asset type, location and vulnerability (***PLAN***). The RIP prioritizes actions to incorporate resilience into the Division's project development process to discover new projects to initiate, as well as existing projects to enhance (***IMPROVE***). The RIP defines the Division's framework for maintaining existing assets to reduce risk to extreme weather events (***MAINTAIN***) and emergency response plans to react and recover quickly from natural disasters (***RESPOND***). The RIP presents a strategy for the Division to continue working closely with municipalities, regional planning organizations and others throughout the Commonwealth on this approach to resilience (***INFORM***). This approach and related actions are summarized in **Appendix 2.**

Part of these efforts include advancing goals that MassDOT is a partner or lead on in the 2018 and 2023 SHMCAP update: ResilientMass Plan. Action items from these plans are identified in the RIP with the ResilientMass logo ( ). Additional information on ResilientMass Plan action items can be found online: ResilientMass Plan Action Tracker. The RMAT maintains this tracker to reflect progress in implementing the ResilientMass Plan's actions across all State Agencies.

ResilientMass

Completed actions, progress to date and proposed new work are noted for each component of the resiliency approach. MassDOT anticipates the actions will evolve as progress is made, however, this approach serves as the foundation. Progress on many of these actions is dependent on the success of MassDOT's Federal grant application for a PROTECT planning grant and other new operations and capital funding.

1: PLAN

Goal:

Prepare for changing conditions and extreme events through vulnerability assessments and identify criteria to evaluate transportation asset vulnerabilities.

Completed Actions:

- Massachusetts Coastal Flood Risk Model.
  - » Funded the development of the Massachusetts Coastal Flood Risk Model (MC-FRM), which publicly provides the following for the entire coastline of Massachusetts through ResilientMass: probability exceedance maps, projected water surface elevations, projected wave heights and projected wave action water surface elevations for 2030, 2050 and 2070 SLR scenarios.
- Deerfield Watershed Stream Crossing Resilience Pilot Project.
  - » Completed the Deerfield Watershed Stream Crossing Resilience Pilot Project, which ranked the vulnerability of culverts and wildlife to climate chaEnge within the watershed.
- Stream and River Crossing Vulnerability Assessment.
  - » Completed a stream and river crossing vulnerability assessment of approximately 1,100 department-owned culverts and 2,700 bridges as part of the 2019 MassDOT - FHWA Pilot Project: Asset Management, Extreme Weather, and Proxy Indicators Project. Results were summarized in the MassDOT Highway Division Transportation Asset Management Plan (TAMP).
- Implemented several recommendations frEom the Commission on the Future of Transportation.
  - » Implemented several recommendations from the Commission on the Future of Transportation in the Commonwealth, including the performance of vulnerability assessments (described in **Section 3**), reliability and modernization investments in the TAMP, and the development of bicycle, pedestrian, and electrical vehicle infrastructure deployment plans.
- Flood Risk Assessment for MassDOT Highway District One.

Massachusetts Coast Flood Risk Model

As described in Section 3, in 2015 MassDOT Highway Division and FHWA co-funded a pilot project to assess the current and future vulnerabilities of the CA/T system in Boston to coastal storm surge from the effects of nor'easters, hurricanes, and SLR, referred to as the BH-FRM. One of MassDOT's commitments under the 2018 SHMCAP was to build upon the BH-FRM and develop the Massachusetts Coast Flood Risk Model (MC-FRM), which was completed in early 2022. Data has been provided to Massachusetts Coastal Zone Management (CZM) office who will manage and maintain the model going forward. Data are available publicly and is incorporated into the RMAT Climate Resilience Design Standards Tool.

On-going and In-Progress Actions:

- Massachusetts Statewide Hydraulic Modeling Project.
    - » This is a collaboration between Massachusetts Department of Environmental Protection (MassDEP), MassDOT, United States Geological Survey (USGS), and UMass Amherst. Municipalities expressed concerns about the cost of meeting the stream crossing standards, so MassDEP developed a guidance document on what constitutes "maximum extent practicable." Key considerations include:
        - » Aquatic connectivity will be essential for maintaining populations of vulnerable species of fish and wildlife.
        - » Structures that meet stream crossing standards are more resistant to storm damage and will be better suited for more severe storms due to climate change.
        - » Minimum hydrology and hydraulic (H&H) standards are needed to protect flood and storm damage prevention "interests" of the Wetlands Protection Act (WPA). There is an opportunity to account for future flood flows in H&H standards.
    - » The goal of this project is to give communities the ability to create a preliminary design for new or replacement stream crossings. This will help communities facilitate permitting of replacement projects that will meet the WPA requirements while minimizing associated adverse impacts and will provide a preliminary evaluation of H&H and ecological conditions for potential replacement projects.

- Capture Institutional Knowledge through Mapping our Vulnerable Infrastructure Tool (MOVIT).
    - » MassDOT continues this ongoing effort to update previously collected information and collect new information, which is accessible through GeoDOT.

- Partnering with MassWildlife to incorporate habitat and fisheries considerations into MassDOT assessments, projects and planning.
    - » MassDOT has incorporated a variety of data layers into MaPIT to review projects against fisheries, wildlife and vulnerability considerations during the earliest stages of the project development process.
    - » MassDOT has an interagency working group/partnership with MassWildlife and the Division of Marine Fisheries to prioritize fish and wildlife passage opportunities within MassDOT projects. The partnership is also working on a guide for designers to help determine what design-related best management practices may be appropriate for their project location.

Future Actions:

- Develop resiliency screening parameters based on vulnerability assessments and best practices.
    - » Based on findings from the ResilientMass Plan and other completed assessments, develop additional parameters to screen for and prioritize resilience improvements in vulnerable areas. MassDOT Highway Division will create a library of past assessments and identify screening parameters and corresponding best practices based on location, asset and hazard. Once developed, the screening parameters will be used to identify priority projects for the RIP list, coordinate with other agencies and engage stakeholders, as applicable, through the project development process.
- Develop resiliency framework for MassDOT Metropolitan Highway System, including operated tunnels and underpasses.
    - » Tunnels and underpasses are increasingly vulnerable to the impacts of climate change and extreme weather events that are expected to become more frequent and intense. The proposed research aims to develop a resiliency framework tailored for MassDOT tunnel and underpass infrastructure assets in Massachusetts. The framework will build off the results of past studies and validate the efficiency of past models. The framework will serve as a guide for identifying vulnerabilities of such assets and providing specific recommendations and best practices to enhance their resiliency.

- Integrate freight system assets into resilience plans.
    - » Consistent with the Freight Plan and Beyond Mobility, MassDOT will assess the vulnerability of freight system assets and operations and identify priority actions to protect the system from climate change and extreme weather impacts.

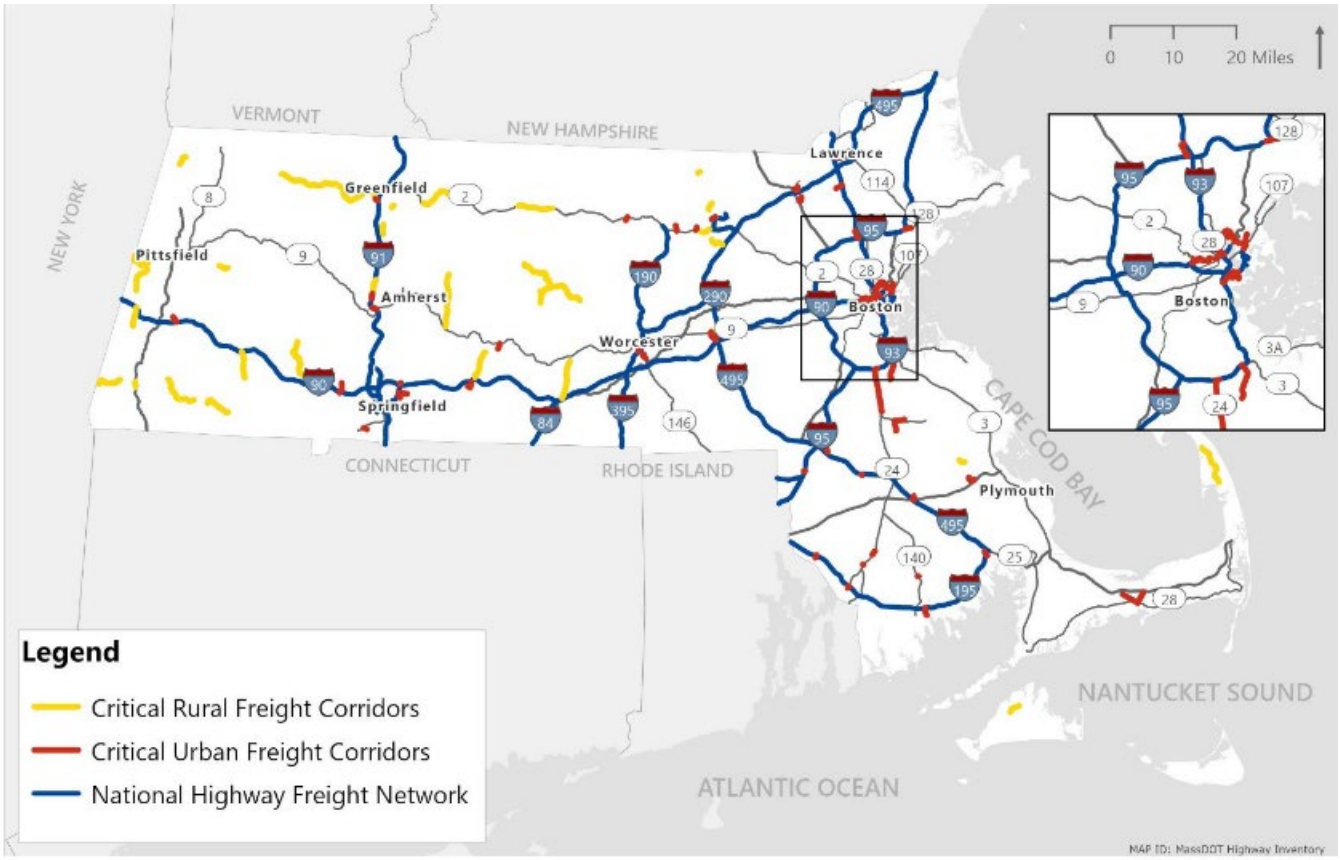


Figure 4.1.1: Roadway infrastructure freight designations in Massachusetts in 2023.
(Source 2023 Massachusetts Freight Plan and FHWA.)

2: IMPROVE

Goal:

Incorporate resilience measures into projects and initiate resiliency-focused projects.

Completed Actions:

- Supported development of the Massachusetts Climate Design Standards Tool.
- Integrated climate resilience into capital planning activities and State Transportation Improvement Program (STIP) process.
- Updated MaPIT to screen and score for environmental, social equity and health effects.
- Updated project initiation scoresheet screening criteria and scoring with climate resilience questions.
- Updated MassDOT's Environmental Review Checklist (ERC), to include climate resilience questions.
- Established a Rivers and Roads Training Program.
- Updated Bridge Design Manual to ensure projects consider future changes in hydrologic conditions.
  - » MassDOT released the Hundredth Anniversary Edition of the Bridge Design Manual in June 2024: https://www.mass.gov/manual/massdot-bridge-manual-hundredth-anniversary-edition. The Hydrology and Hydraulics section updated manual includes guidance for applying climate change to hydrologic analyses and selecting hydraulic design flood frequencies based on the resources identified in Table 4.2.1.

Massachusetts Climate Resilience Design Standards Tool (RMAT Tool)

MassDOT participated in the development of the standards and guidance that informed the RMAT Tool. The goal of the project was to better incorporate climate resilience into the State's capital planning process for projects with buildings, infrastructure and/or natural resource assets. The project resulted in the creation of the RMAT Tool: an interactive web-tool that provides a preliminary climate risk screening and recommended climate resilience design standards for projects. The RMAT Tool is required for State grant applications and projects that go through the MEPA environmental review process.

On-going/In-progress Actions:

- Use MassDOT's Highway Division Project Scoresheet for project initiation and prioritization.
  - » This scoresheet is an Excel-based framework for developing project profiles by gathering data from project managers and subject matter experts, including flood and climate change resiliency. The process is further aided by using MaPIT to automatically screen proposed project locations against environmental, hydrological, system condition, equity and safety layers. This information is then saved in MassDOT's ProjectInfo system.

- Complete the MassDOT ERC prior to scoping of a project.
    - » Once a project has been initiated, scope development in advance of preliminary design (pre-25-percent scoping) presents an additional opportunity to review project location for vulnerability and determine if there are opportunities to improve resiliency within the design. The MassDOT ERC, effective May 2023, includes four questions specific to resiliency, but also incorporates questions related to stormwater control measures to mitigate flooding and erosion and compliance with the stream crossing standards. The ERC is completed by a MassDOT environmental analyst prior to scoping the project. Their responses and findings are confirmed with the project's design consultant, and the consultant provides additional responses, actions and supporting documentation with the 25-percent design submission. This was also a 2018 SHMCAP action item and will undergo periodic updates to support MassDOT's current processes.
- Complete the RMAT Tool for projects that are required to go through MEPA environmental review.
    - » If a project is required to go through the MEPA environmental review process, the project must be entered into the RMAT Tool per the MEPA Interim Protocol described in **Section 2**. The RMAT Tool provides preliminary information about project exposure and risks to assets entered, as well as recommended design standards to account for SLR, changes in extreme precipitation and extreme temperatures. The recommended design standards are intended to provide a consistent basis-of-discussion throughout the Commonwealth and across State agencies, including MassDOT. The RMAT Tool also provides associated guidelines to support site suitability, regional coordination and flexible adaptation strategy development. MassDOT considers the outputs from the RMAT Tool but continues to prioritize site-specific data and analysis to inform project design. GHG emissions are considered for major projects as part of the NEPA process.

There are many Federally developed resources available that have supported MassDOT Highway Division with implementing climate resilience improvements. These resources are updated frequently and available through the USDOT Climate Center.

Table 4.2.1: Resilience Design Manuals

RESOURCE	DESCRIPTION OF MASSDOT USE OF RESOURCE
FHWA Hydraulic Engineering Circular (HEC) 17, "Highways in the River Environment: Extreme Events, Risk and Resilience" (2016)	The HEC-17 manual provides guidance and methods to assess transportation infrastructure exposure to extreme flood events considering climate change. MassDOT's Flood Risk Assessment corresponded with what HEC-17 would consider to be a Level 5 analysis; the assessment explored and developed a full range of climate projections and used them as inputs into a hydrologic model to derive projected future discharges. HEC-17 was used to develop the Hydrologic Analysis section of the MassDOT Bridge Design Manual - Hundredth Anniversary Edition.
National Cooperative Highway Research Program (NCHRP) 15-61, "Applying Climate Change Information to Hydrologic and Hydraulic Design of Transportation Infrastructure" (2019)	The NCHRP 15-61 guidance document provides a comprehensive framework for considering and, where appropriate, incorporating climate change into inland hydrology and coastal analyses, building on the HEC-17 methods. The RMAT Tool recommendations for extreme precipitation were developed based on the NCHRP 15-61 methodology. NCHRP 15-61 was used to develop the Hydrologic Analysis and Hydraulic Design Flood Frequency sections of the MassDOT Bridge Design Manual - Hundredth Anniversary Edition.
FHWA "Nature-Based Solutions for Coastal Highway Resilience: An Implementation Guide" (2019)	This guide helps transportation practitioners understand how and where nature-based and hybrid solutions can be used to improve the resilience of coastal roads and bridges, including in the project planning and delivery processes. MassDOT is coordinating with the Massachusetts Coastal Zone Management Office, as noted in the guide, on projects within the coastal zone and as part of the Resilient Coasts Plan.
FHWA HEC-25, "Highways in the Coastal Environment" (2020)	The HEC-25 manual provides the best available and actionable engineering and science on coastal resilience within a framework that is adaptable to future improvements, including steps to identify and implement nature-based solutions in the design process. This manual provides guidance for MassDOT hydraulics engineers and supports planning, design and operation of highways in the coastal environment to make them more resilient. HEC-25 was used to inform the Hydraulic Design Flood Frequency section of the MassDOT Bridge Design Manual - Hundredth Anniversary Edition.
FHWA "Addressing Resilience to Climate Change and Extreme Weather in Transportation Asset Management" (2023)	This handbook provides a practical set of options for integrating resilience to extreme weather events and climate change into asset management practices and policies. This handbook was developed prior to the BIL amendment that requires State DOTs to consider extreme weather and resilience in TAMP lifecycle cost and risk management analyses [23 U.S.C. 119(e)(4)(D) § 11105]. MassDOT's FHWA-funded asset management pilot project is showcased in the handbook and was one of the pilot studies used to develop this handbook. MassDOT will continue to comply with regulations for States to consider resiliency and extreme weather in asset management plans per 23 U.S.C. 119(e)(4)(D) § 11105.

Future Actions:

- Enhance resiliency screening in project development.
  - » Incorporate screening criteria and results from future actions identified in "Plan" component into MaPIT. This additional integration of the screening criteria and assessment results will support identifying and prioritizing resilience-focused projects.
  - » Assess if there are general design elements and best practices that can be identified at project scoping. Research best practices and leading examples of transportation asset resilient designs and standards to inform future MassDOT initiatives and design guidance.
  - » Prepare a summary of findings. Develop standards based on project type/location to evaluate if applicable or not.
- Build out internal organizational structure to support implementation of the RIP.
  - » The completed and ongoing/in-progress actions summarized in the RIP have been championed by multiple sections across MassDOT's Highway Division, including the Environmental Section, Policy Group, Program Management, Project Management, Design Section, Operations and Maintenance, and Hydraulics Section. Future actions require additional human resources and internal and external coordination. MassDOT's Highway Division kicked off an Internal Working Group to begin this effort. Additional training and workflows will be needed as new screening criteria, RIP performance measures and other actions become adopted into practice.
- Identify opportunities to track climate resilience and/or reduce vulnerabilities in project development.
  - » Review the Transportation Research Board (TRB)'s self-assessment tool to identify opportunities to incorporate components into the project review process. This will focus on opportunities for reducing hazards and climate change concerns through the project screening and implementation process.
- Expand internal and external training for the Rivers & Roads program.
  - » Invest in internal and external training, including continuation of the fluvial geomorphology based "Rivers & Roads" training program, which provides guidance on bridge and culvert design interaction with emerging fluvial geomorphology practices. Coordinate with resource agencies on this effort, as needed. Update existing guidance documents to confirm proposed bridge and culvert projects are appropriately sized. Conduct internal staff training to verify projects are reviewed for compliance with the stream crossing standards.

Fluvial geomorphology

studies the ways that rivers move and change over time, focusing on how the flow of water interacts with the movement of sediment – dirt, sand, gravel, boulders – and debris.

Planning/ Scoping

MassDOT Highway Division's Project Scoresheet includes resiliency considerations.

MaPIT automatically screens proposed project locations against environmental, system condition, equity and safety layers.

ERC includes questions related to resiliency and stormwater control measures at scoping.

Design/ Construction

Projects going through MEPA environmental review process use the RMAT Tool.

Added a "Climate Change Indicator" subsection as part of the updates to the MassDOT Bridge Design Manual.

Established a Rivers & Roads training program and expanding internal and external training.

Regularly use resilience reference manuals available through the USDOT Climate Center.

Operations/ Maintenance

Developing a Programmatic Operations and Maintenance Plan for drainage system maintenance given more frequent and severe storm events.

Updated MassDOT standards to align with resiliency best practices relating to pavement mixture, preservation projects, and existing and new bridges.

Capturing institutional knowledge and increasing awareness of vulnerabilities.

Figure 4.2.1: Holistic resiliency integration across MassDOT project lifecycle.

3: MAINTAIN

Goal:

Reduce disruption from extreme weather and changing conditions to existing assets over their service life through maintenance, planning and coordination.

Completed Actions:

- Considered extreme weather and resilience in the lifecycle cost and risk management analyses in the 2023 TAMP.
  - » Updated in the Fall of 2023, the TAMP documents MassDOT's progress toward a long-term SOGR in its pavement and bridge assets in accordance with 23 CFR 515.7. The TAMP outlines several best practices that have already been incorporated into MassDOT standards to increase resilience of Highway Division assets and considers lifecycle costs and risk management analyses.

Table 4.3.1: Best Practices to increase resilience outlined in TAMP

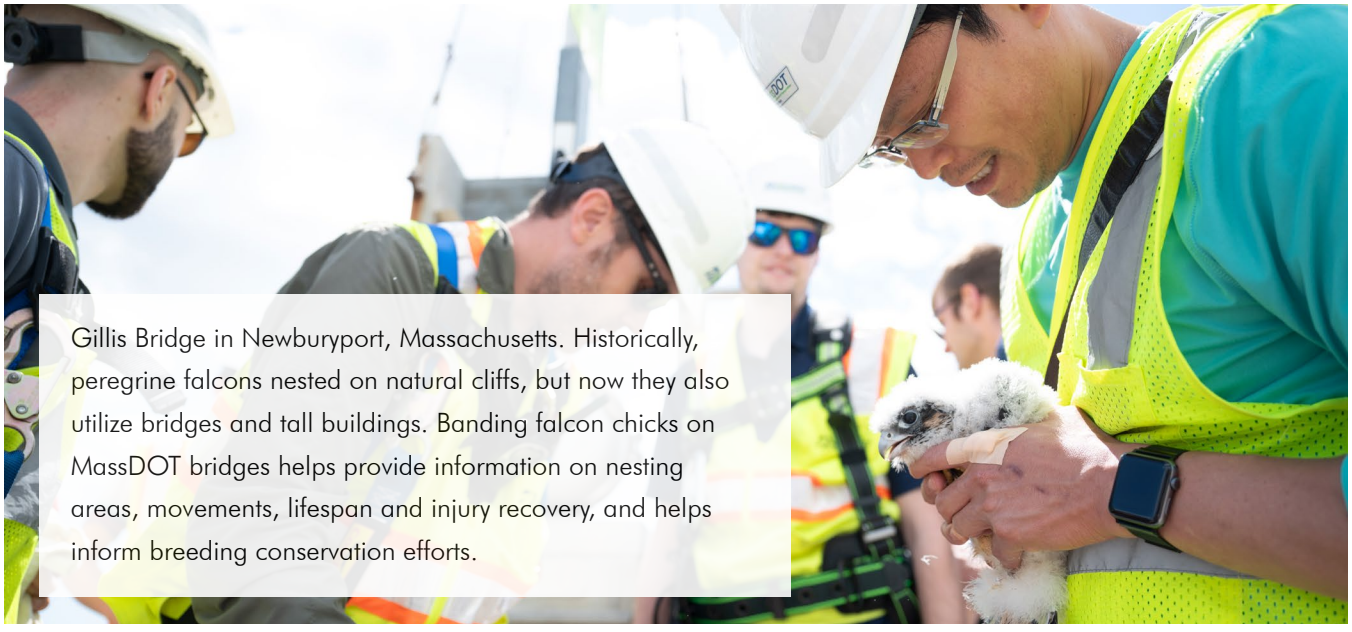
Pavement Mixture	• Modify all types of pavement mixtures to provide additional stability in high temperatures. • Incorporate Balanced Mixture Design methods in all future Hot Mix Asphalt mixtures to better balance mixture cracking and moisture damage.
Preservation Projects	• Include drainage system cleaning and repairs to reduce impacts during extreme weather events. • Leverage open-graded friction course on limited access roadways to reduce risk of water sheet flow, tire spray and hydroplaning.
Existing Structures (Bridges)	• Routine inspection and targeted post-storm inspection of scour-susceptible structures. • Require "closed-loop" systems on all vendor vehicles for winter deicing treatment to limit material overuse and reduce risk of infiltration into superstructure and substructure elements.
New Structures (Bridges)	• Multi-disciplined scoping to identify appropriate criteria and standards for hydraulic analysis. • Incorporate link slabs and slab-over-backwall details to reduce risk of winter deicing treatment infiltrating into superstructure and substructure elements.

On-going/In-progress Actions:

- Work with MassDOT District offices on maintenance planning and geospatial tracking of assets and vulnerabilities.
- Bridge Inspection Program.
  - » MassDOT Bridge Inspection Program includes routine inspection and targeted post-storm inspection of scour-susceptible structures.
- Fund and implement the Programmatic Operations and Maintenance Plan (POMP).
  - » In 2023, MassDOT's Environmental Section, Asset Management and District offices partnered to outline an approach for a POMP to institute a structured, systematic approach for drainage system inspections and maintenance. The centerline of MassDOT roadways is serviced by more than 125,000 catch basins and a critical component to safe and reliable roadways is a properly functioning drainage system. In addition to routine maintenance, MassDOT personnel inspect high-priority areas with flood risk prior to forecasted storm events to improve preparedness. As legacy infrastructure ages and storm events become more frequent and severe, MassDOT is developing a structured, systematic approach for maintaining the functionality of MassDOT's drainage systems, which, in turn, satisfies the objectives of roadway safety and environmental protection.

Future Actions:

- Conduct comprehensive culvert mapping.
- Implement culvert inspection program.
- Conduct comprehensive drainage inventory mapping.
- Establish extreme weather and maintenance working group.



Gillis Bridge in Newburyport, Massachusetts. Historically, peregrine falcons nested on natural cliffs, but now they also utilize bridges and tall buildings. Banding falcon chicks on MassDOT bridges helps provide information on nesting areas, movements, lifespan and injury recovery, and helps inform breeding conservation efforts.

4: RESPOND

Goal:

Build and maintain capabilities to respond to and quickly recover from disruptions from extreme weather and changing conditions.

Completed Actions:

- Coordinated with local, State and Federal partners on the Cape Cod Emergency Traffic Plan (CCEPT).
    - » The CCEPT provides a framework for the coordination and management of traffic operations to facilitate the egress of a high volume of traffic from Cape Cod in the event of a hurricane or other hazard, particularly during peak tourist season. In addition, the CCTEP details anticipated operations in the event an emergency temporary shelter needs to be activated at Joint Base Cape Cod (JBCC) to accommodate displaced motorists unable to exit Cape Cod due to the closure of the Bourne and Sagamore Bridges. The CCETP was developed by the Massachusetts State Police (MSP) and MEMA, in cooperation with the Bourne and Sandwich Police Departments, MassDOT, Massachusetts National Guard (MA-ARNG), JBCC, U.S. Army Corps of Engineers (USACE), Barnstable County Sheriff's Department, American Red Cross (ARC), and other State agencies and local emergency management agencies from towns across Cape Cod.
- Developed Critical Transportation Need (CTN) Evacuation Operations Annex as part of the Massachusetts Comprehensive Emergency Management Plan.
    - » The CTN Evacuation Operations Annex provides the framework, functions and procedures necessary to implement a State-supported evacuation of individuals who do not have access to personal transportation resources. It is an annex to the State's Evacuation Coordination Plan. Under this plan, MassDOT conducts planning and response with MEMA, the MBTA and Regional Transit Authorities, among others, for this scenario.

On-going/In-progress Actions:

- Maintain readiness to respond with multiple transportation modes as the primary State agency for Massachusetts Emergency Support Function 1 (MAESF-1): Transportation Annex.
    - » MassDOT is the primary State agency responsible for MAESF-1 and is supported by the Department of Conservation and Recreation, Massachusetts Port Authority, MSP and the Steamship Authority.
    - » An annex to the Massachusetts Comprehensive Emergency Management Plan, MAESF-1: Transportation provides a framework for coordination and cooperation across State agencies regarding transportation needs, issues and activities before, during and after a disaster, emergency or planned event in the Commonwealth. This Annex details how the Commonwealth will provide transportation-related support and assistance to jurisdictions in the event local needs exceed available resources during an emergency.

- Regularly participate in "all hazards" emergency planning, training and exercises with local, State, Federal and other parties.
  - » As the responsible agency for MAESF-1, MassDOT regularly participates in emergency planning, training and exercises with local, State and Federal parties, and with multiple transportation modes, including air, rail and transit. These exercises provide an opportunity for testing emergency planning and response assumptions, identifying interdependencies among different community lifelines, building relationships at multiple levels of government and with private sector stakeholders, and verifying readiness to respond to extreme weather events.
- Maintain readiness to respond and reduce disruptions due to extreme weather and changing conditions through various systems.
- Monitor weather forecasts by National Weather Service and contract weather service providers.
  - » Storm preparations and response plans are based on weather forecasts, and the Highway Operations Center (HOC) issues severe weather alerts to the public.

Future Actions:

- Integrate findings from vulnerability assessments into emergency management and operations response plans.
  - » Use the flood risk models and data from the vulnerability assessments to identify current and future high-risk areas and strengthen emergency management with local, State and Federal agencies.
- Coordinate with other divisions within MassDOT on opportunities for disaster assessments.
  - » As one of the action items in Beyond Mobility, MassDOT Aeronautics Division will explore the use of unmanned aerial systems (UAS) to assess the impacts of natural disasters on transportation infrastructure and assist in emergency response.

USING EMERGENCY EXERCISES TO EXPLORE INTERDEPENDENCIES AND COLLABORATE ACROSS INFRASTRUCTURE OPERATORS

In October 2020, MassDOT participated in a regional exercise with six municipalities, State and Federal agencies, and community-based organizations to identify critical infrastructure points of failure in the densely populated Lower Mystic region following a simulated 2050 1-percent annual chance nor'easter storm. Key regional issues and interdependencies highlighted through this exercise included:

Power and flood vulnerabilities of the Amelia Earhart Dam

General roadway access and flood vulnerability of MassDOT's tunnel system

Widespread reliance on emergency generators

Environmental concerns related to Chelsea Creek fuel terminals

Flood vulnerability of MBTA routes and time needed to replace damaged assets

Access to medical care during and immediately after a major event

Flood water management

Communication with MEMA as a central point of information and coordination

Massachusetts Highway Operations Center

The mission of the Highway Operations Center (HOC) is to provide a reliable and sustained means of monitoring state roadways and facilities, maintaining workplace and public safety on a 24-hour basis. It is responsible for detecting roadway incidents, receiving reports of roadway incidents, responding to facility alarms, managing security systems, and coordinating traffic operations, maintenance and emergency response activities.

The dashboard on the display wall of the Highway Operations Center.

Photo Source: Esri Case Study: Massachusetts Department of Transportation Integrates Real-Time Traffic Feed with ArcGIS Velocity to Boost Emergency Response

The HOC manages an event classification and notification system, providing reports to MassDOT personnel and external entities throughout the course of an incident until normal operations have been resumed. In addition, the HOC provides the appropriate deployment of resources to an incident, augments traffic management systems, if necessary, provides information to roadway users, and oversees the use of various life-safety and intelligent transportation systems (ITS). The HOC strives to create a common operating picture and provide real-time situational awareness to other transportation and public safety agencies to cooperatively respond to any threat to the transportation system.

The HOC manages roadway conditions and incident monitoring systems, various automated roadway operating systems, and disseminates information on roadway conditions and incidents to MassDOT and external agencies, leveraging traffic management systems, surveillance systems and communications protocols through established networks.

The HOC's capabilities are housed in three redundant locations. The main HOC (HOC-BOS) is located in South Boston adjacent to I-90. There are two backup HOCs (BHOC); one is located in Vent Building 6 (HOC-VB6), which is connected to the Ted Williams Tunnel. The other is located in the Central Massachusetts Transportation Center in Worcester (HOC-WOR). These locations are fully redundant and can be operated simultaneously or independently.

The HOC/BHOC is staffed by qualified, trained personnel and equipped with the essential apparatus and equipment necessary to communicate with, supervise, and coordinate all personnel, using the features of the Integrated Project Control System (IPCS) and other systems. On a regular basis, the HOC staff schedule and conduct evacuation drills of the HOC simulating various system failures that require deployment of staff to the BHOC for activation of back-up emergency operations.

5: INFORM

Goal:

Coordinate MassDOT Highway Division's resilience approach with ResilientMass, municipalities, municipal planning organizations and the public.

Completed Actions:

- Participated in the development of the 2018 Statewide Hazard Mitigation and Climate Adaptation Plan, and the 2023 update, dubbed the ResilientMass Plan.

On-going/In-progress Actions:

- Coordinate with State and Federal partners on resilience initiatives and regulations.
  - » MassDOT looks forward to working with Federal partners to coordinate and determine how Federal regulations, such as the Surface Transportation Uniform Relocation Assistance Act, will be applied in the future. MassDOT continues to coordinate with the Coast Guard on a project-by-project basis on navigability needs and concerns.
- Encourage sustainable and resilient transportation through permit granting authority.
  - » Through MassDOT's review of private development projects in need of access to the state highway system, developers are required to provide mitigation that generally aligns with MassDOT Highway Division's resiliency goals. MassDOT seeks to reduce trip generation through transportation demand management measures that could lead to reduction in the footprint of parking or highway widening, thereby reducing impervious surface. These are currently implemented through MassDOT's review processes; however, MassDOT expects to issue new Transportation Impact Assessment guidelines in the future that would formalize these practices.
- Communicate known MassDOT Highway vulnerabilities and resilience actions.
  - » MassDOT conducts robust public participation processes for agency planning initiatives mentioned in this plan, such as the STIP and Beyond Mobility. Through these processes, MassDOT is able to share information regarding assets, plans and priorities with communities and industry partners, as well as learn about communities' transportation vulnerabilities and priorities.
- Engage in collaborative resilience building with State, regional and municipal partners.
  - » MassDOT Highway Division collaborates and communicates with other State agencies and the RMAT to integrate transportation asset information in climate risk assessments, including the 2022 MA Climate Assessment and Resilient Coasts Strategy.

Future Actions:

- Coordinate with Municipal Vulnerability Preparedness (MVP) program to identify priority transportation projects.
  - » Since 2018, the MVP program has awarded more than 380 grants to cities and towns across Massachusetts to implement priority actions to build resilience. At least 55 of those grants have included a focus on transportation asset resilience, including roadways, culverts and/or bridges. MassDOT will explore the creation of a State-managed discretionary capital improvements program focused on soliciting resiliency projects from communities based upon vulnerability assessments performed as part of planning grants through the MVP program.

MASSACHUSETTS MUNICIPAL VULNERABILITY PREPAREDNESS (MVP) PROGRAM

The MVP program assists cities and towns in identifying and addressing their vulnerabilities to climate change and natural hazards, and provides grants for communities to assess risks, develop strategies and implement actions that enhance resilience. This program is administered by EEA and includes, among its core principles, increasing equitable outcomes for EJ and other priority populations, using climate change data for a proactive solution, and employing nature-based solutions. The MVP Planning Grant 2.0 allows communities to revisit resilience priorities defined during past planning processes with the involvement of the wider community and includes new training and guidance on strategies for building climate resilience, equity and climate justice.

- Integrate Metropolitan Planning Organization (MPO) risk assessments into the RIP.
  - » MassDOT Highway Division works through its District Offices, Regional Planning Organizations, other State agencies and with municipal partners to understand and communicate transportation risks and vulnerabilities statewide. Most municipalities across the Commonwealth have completed Hazard Mitigation Plans (HMP). These plans include a risk assessment, actions to help mitigate the impact of natural and manmade hazards, and provide long-term planning to make communities more resilient and better able to withstand and recover from disasters. Federal funding through FEMA programs, such as Building Resilient Infrastructure and Communities (BRIC), may be used for projects that align with the HMP.
- Update RIP to reflect results from on-going and future actions.
  - » As studies are completed or updated, planning efforts with other transportation modes and stakeholders advance, and new priority projects are identified, the RIP will be updated.

Hamlin Street Bridge Replacement Project in Acushnet, Massachusetts. The new bridge meets Massachusetts River and Stream Crossing Standards and replaced a diadromous fishway to protect Migratory Herring and American Eel populations.

SECTION 5: INVESTMENT PLAN

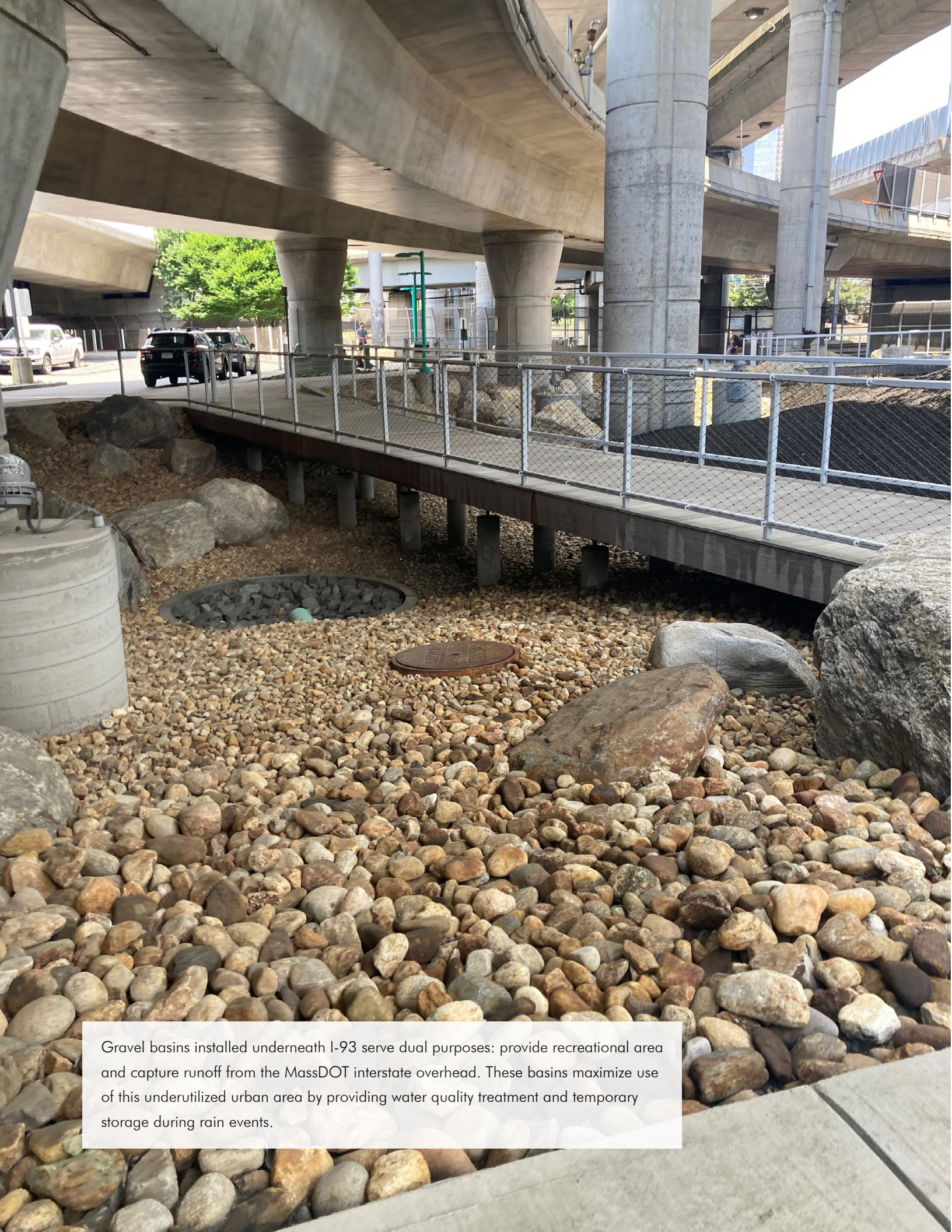
MassDOT is investing in resilience through the Capital Investment Plan (CIP), STIP and SLRTP. MassDOT Highway Division is committed to integrating resiliency into existing projects and advancing identified, stand-alone resiliency projects. Additionally, planning and operation investments to support resiliency efforts will be considered and advanced. Several priority resilience projects are included in **Appendix 3;** the project list focuses on known vulnerabilities and needs from District Maintenance offices. The inclusion of the priority project list supports prioritized funding and eliminates the need for a benefit cost analysis (BCA) if PROTECT discretionary grant funds for the projects are pursued. The list of priority projects in **Appendix 3** is not a comprehensive list; the list is intended to grow as MassDOT Highway Division continues to holistically identify resiliency projects, as described in **Section 4**, informed by the risk assessments described in **Section 3**. MassDOT Highway Division will coordinate with the Federal Highway Administration (FHWA) to update the list of resilience priority projects as they are identified through the project development process and pending results of completed risk assessments.

MassDOT Investment Planning: Released in July 2023, the 2024–2028 CIP includes a plan for investing a total of $15.7 billion in capital improvement projects for MassDOT and MBTA throughout the next five years. As part of MassDOT's annual submission to the Massachusetts Executive Office for Administration and Finance (A&F), MassDOT is required to identify what portion of investments address climate change and provide resiliency for the transportation network. Approximately 60-percent of investments focus on improving the reliability and resilience of the existing core transportation system. Climate resilience is one of the scoring criteria in the annual STIP process through the project initiation process described in **Section 4**.

New Program in STIP/CIP: Highway Resiliency Improvements

With the passage of the BIL, MassDOT has Federal funding for resilience through the PROTECT program formula funds and is eligible to pursue additional Federal funding through the PROTECT program discretionary grants. As of May 2024, the anticipated PROTECT programming for Massachusetts is $105 million over five years per the draft MassDOT CIP. MassDOT is required to set aside at least 2-percent of the annual PROTECT formula funds for resilience planning activities, which can be used to support resilience planning, predesign or design; technical capacity-building; or evacuation planning and preparation.

Beyond Mobility: Beyond Mobility is a SLRTP that will guide the work of MassDOT through 2050. The scope of the SLRTP is statewide and encompasses immediate and long-range planning activities. MassDOT has intentionally placed public engagement at the center of the Beyond Mobility planning process, with a focus on equitable and inclusive outreach. Resiliency is one of the six priority areas, and the vision for Beyond Mobility is "by 2050, significant investments to mitigate climate threats have protected transportation assets against natural hazards and climate change impacts." The resiliency action items identified in Beyond Mobility for MassDOT Highway Division are represented in the actions identified in **Section 4**. Beyond Mobility captures all MassDOT divisions, including each modal division and all shared services. The RIP is incorporated in Beyond Mobility as an appendix.

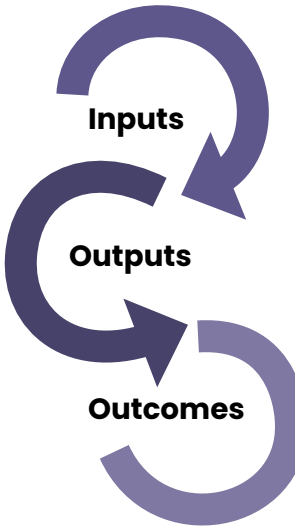


Gravel basins installed underneath I-93 serve dual purposes: provide recreational area and capture runoff from the MassDOT interstate overhead. These basins maximize use of this underutilized urban area by providing water quality treatment and temporary storage during rain events.

SECTION 6: PERFORMANCE MEASURES

Measuring progress toward achieving resiliency as described in this RIP is an important future step. MassDOT Highway Division has implemented performance measures for similar agency plans, including the Massachusetts Pedestrian Transportation Plan and Massachusetts Bicycle Transportation Plan, and anticipates taking a similar approach for resiliency performance measures.

The approach for measuring performance considers MassDOT Highway Division actions as **inputs** and the controllable results as **outputs. Outcomes** are measurements toward the goals identified in **Section 4** for Plan, Improve, Maintain, Respond and Inform.



As MassDOT Highway Division monitors the progress of RIP implementation, an additional action planned is to develop and formalize output measures with interim and long-term targets. MassDOT Highway Division aims to be aligned, to the extent practicable, with other State and Federal performance measurement initiatives, including proposed performance metrics for the PROTECT program and ResilientMass initiative. The RIP is intended to be a living document that will be updated as new information and projects become available.

The Leonard P. Zakim Bunker Hill Memorial Bridge in Boston, Massachusetts.

APPENDICES

Appendix 1. Climate Projection Data

MassDOT Highway Division's Resilience Improvement Plan is informed by the following risk-based vulnerability assessments:

- MassDOT – FHWA Pilot Project: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery (Completed 2015)
- Massachusetts State Hazard Mitigation and Climate Action Plan (Completed 2018)
- MassDOT Deerfield Watershed Stream Crossing Resilience Pilot Project (Completed 2018)
- MassDOT - FHWA Pilot Project: Asset Management, Extreme Weather and Proxy Indicators Pilot Project (Completed 2019)
- Massachusetts Climate Change Assessment (Completed 2022)
- ResilientMass Plan (State Hazard Mitigation and Climate Action Plan) (Completed 2023)
- MassDOT - Flood Risk Assessment (completed for District One in 2024)

These assessments integrated historic climate observations and/or future climate projections from the sources listed in the following table.

DATA SET	YEAR PUBLISHED OR UPDATED	HISTORIC, FUTURE, BOTH	BRIEF DESCRIPTION	2024 FLOOD RISK ASSESSMENT	2023 RESILIENTMASS PLAN	2022 MA CLIMATE ASSESSMENT	2019 FHWA PILOT: ASSET MANAGEMENT	2018 DEERFIELD WATERSHED PILOT	2018 SHMCAP	2015 FHWA PILOT: CENTRAL ARTERY
Early Detection and Distribution Mapping System; University of Georgia Center for Invasive Species and Ecosystem Health	2023	Historical	This source tracks user reports of invasive species locations.		X					
National Water Dashboard; USGS	2023	Historical	This source provides water level and quality indicators for groundwater resources, streams, lakes, reservoirs and other water resources throughout the United States.		X					

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Seismic Site Class Map; Research by Marshall Pontrelli, Stephen B. Mabee, and William P. Clement	2022	Historical	This source provides soil classification maps, which were used with Hazus 6.0 for the 2023 ResilientMass Plan.		X					
Cornell University's Stochastic Weather Generator Dataset	2022	Future	This source provides projections of temperature and precipitation variables for four future eras (2030, 2050, 2070 and 2090) for the 10th, 90th and median percentile results. It relies on results from among 20 Global Climate Models (GCMs) for the Representative Concentration Pathway (RCP) 8.5 greenhouse gas emissions scenario.		X	X				
Cornell University's Scaled Intensity-Duration-Frequency (IDF) Curve Dataset	2022	Future	This dataset scales "current climate" IDF curves provided in NOAA Atlas 14 by the theoretical rate of increase in atmospheric moisture holding capacity that is correlated with projected temperature increases. The data are provided for a range of future potential temperature increases.		X	X				
Downscaled Global Climate Models (GCMs) from the Multivariate Adaptive Constructed Analogs (MACA) repository.	2022	Future	The MA Climate Assessment preferentially uses information from the Stochastic Weather Generator or Scaled IDF curves, which synthesize and interpret information from global climate models in readily accessible formats, such as estimates of the number of days exceeding certain temperature thresholds.		X	X				
Metropolitan Area Planning Council (MAPC) Land Surface Temperature Index	2022	Historic	This source provides a spatially downscaled representation of temperature peaks for historical periods, taking explicit account of local heat island and other anomalies. Originally developed for the Greater Boston metropolitan area, this product was extended to all of Massachusetts.		X	X				

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Daily Temperature Records from Weather Stations; NOAA Global Historical Climatological Network	2022	Historical	This source provides daily time series of temperature observations at various weather stations. Used to plot counts of heat waves at various stations.		X					
GridMET Historical Temperature; Climatology Lab	2022	Historical	This source provides gridded historical climate data, including daily temperature.		X					
Repetitive Loss and Severe Repetitive Loss Properties in Massachusetts; National Flood Insurance Program	2022	Historical	This source provides locations of repetitive loss properties and severe repetitive loss properties, based on records from NFIP.		X					
MA Drought Status History; MA EOEEA and MEMA	2022	Historical	This source provides drought status history of different regions in Massachusetts. Data starts in 2001, when the Massachusetts Drought Management Plan was first developed.		X					
Percent of MA in Drought; U.S. Drought Monitor	2022	Historical	The Drought Severity and Coverage Index (DSCI) is an experimental method for converting drought levels from the U.S. Drought Monitor map to a single value for an area. Data tells us the percent of the state covered by each severity type. Used to calculate the number of weeks drought conditions were present in Massachusetts.		X					
Wind Zones; American Society of Civil Engineers	2022	Historical	This source provides ASCE/ SEI 7-22 Risk Category IV wind loads. Georeferenced from an image of the data by Michael Enko.		X					
Tornado Touchdowns; NOAA's NWS Storm Prediction Center	2022	Historical	This source provides 1950-2021 tornado touchdowns.		X					

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Wildfire Hazard Potential; Northeast-Midwest State Foresters Association	2022	Historic	This source provides an index that quantifies the relative potential for wildfire that may be difficult to control. Can be used as a measure to help prioritize where fuel treatments may be needed.		X					
CMIP6 Temperature Projections; NASA Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6)	2021	Future	This source provides gridded downscaled climate projections of daily maximum and minimum temperature from a range of climate models.		X					
Massachusetts Shoreline Change Project; MA Office of Coastal Zone Management	2021	Historical	Through the Shoreline Change Project, the ocean-facing shorelines of Massachusetts have been delineated and statistically analyzed to demonstrate trends from the mid-1800s to 2018.		X					
The Massachusetts Coast Flood Risk Model (MC-FRM)	2021	Future	This source incorporates climate projections, including sea level rise and coastal storm frequency and intensity projections, and processes those projections to develop risk-based climate datasets for water surface elevation, corresponding to "stillwater levels" excluding wave heights, and annual exceedance probability scenario layers, which are the primary outputs used in the MA Climate Assessment. The tool can also generate other outputs, such as wave height, but those were not used in the MA Climate Assessment.		X	X				
Sea, Lake and Overland Surges from Hurricanes (SLOSH) model; NOAA	2021	Both	This source estimates storm surge heights resulting from historical, hypothetical or predicted hurricanes based on atmospheric pressure, size, forward speed and track data. Used the Maximum of Maximum Envelope of Water (MOM) flavor of SLOSH model for this analysis.		X					

DATA SET	YEAR PUBLISHED OR UPDATED	HISTORIC, FUTURE, BOTH	BRIEF DESCRIPTION	2024 FLOOD RISK ASSESSMENT	2023 RESILIENTMASS PLAN	2022 MA CLIMATE ASSESSMENT	2019 FHWA PILOT: ASSET MANAGEMENT	2018 DEERFIELD WATERSHED PILOT	2018 SHMCAP	2015 FHWA PILOT: CENTRAL ARTERY
Tsunami Inundation Zone; NESEC using data from the University of Delaware	2020	Historical	This source provides simulated tsunami inundation zones.		X					
The National Aeronautics and Space Administration's (NASA) North American Land Data Assimilation System Version 2 (NLDAS-2)	Historical data was available for 1979-2020 at time of retrieval	Historical	See https://ldas.gsfc.nasa.gov/nldas.	X						
Massachusetts Climate Change Projections	2018	Future	This source provides downscaled projections for changes in temperature, precipitation and sea level rise for Massachusetts at mid-century (2050s) and end of century (2090s). The values cited are based on the 10-90th percentiles across 28 projections, so they bracket the most likely scenarios. [NOTE: These projections were superseded by Cornell University's Stochastic Weather Generator Dataset in 2022.]				X		X	
Locally Constructed Analogues (LOCA) dataset	2016	Future	See https://waterdata.usgs.gov/blog/locadownscaling/ https://loca.ucsd.edu/what-is-loca/	X						
Boston Harbor Flood Risk Mode	2015	Future	This source incorporates climate projections, including sea level rise and coastal storm frequency and intensity projections, and processes those projections to develop risk-based climate datasets for water surface elevation (corresponding to "stillwater levels," excluding wave heights) and annual exceedance probability scenario layers. [NOTE: The BH-FRM was superseded by the Massachusetts Coast Flood Risk Model in 2021.]						X	X

DATA SET	YEAR PUBLISHED OR UPDATED	HISTORIC, FUTURE, BOTH	BRIEF DESCRIPTION	2024 FLOOD RISK ASSESSMENT	2023 RESILIENTMASS PLAN	2022 MA CLIMATE ASSESSMENT	2019 FHWA PILOT: ASSET MANAGEMENT	2018 DEERFIELD WATERSHED PILOT	2018 SHMCAP	2015 FHWA PILOT: CENTRAL ARTERY
United States Department of Transportation (U.S. DOT) Coupled Model Intercomparison Project (CMIP) Climate Data Processing Tool	2014	Both	The purpose of the CMIP Climate Data Processing Tool 2.1 is to process readily available downscaled climate projections at the local level into relevant statistics for transportation planners. A combination of CMIP3 and CMIP5 models and emissions scenarios were run through the DOT CMIP Processing Tool to support the Deerfield Watershed Pilot.					X		
U.S. Global Change Research Program National Climate Assessment (NAC3)	2014	Both	This source provides the NAC3 report, which summarizes the impacts of climate change on the United States. The NAC3 Report incorporates projections from three sets of model simulations, including 25 representations of different models from CMIP3, completed for the Fourth IPCC assessment, which were used as the foundation for most of the report findings; 30 representations of different models from CMIP5, completed for the Fifth IPCC assessment, which were leveraged primarily for comparison purposes; and six regional climate model analyses from the NARCCAP regional climate model analysis for the continental US run for current/past (1971-2000) and projected (2041-2070) time periods.					X	X	
Slope Stability; UMass Amherst	2013	Both	This source provides a map showing the location of areas where slope movements have occurred or may possibly occur in the future under the right conditions of prolonged antecedent moisture and high intensity rainfall.		X				X	

DATA SET	YEAR PUBLISHED OR UPDATED	HISTORIC, FUTURE, BOTH	BRIEF DESCRIPTION	2024 FLOOD RISK ASSESSMENT	2023 RESILIENTMASS PLAN	2022 MA CLIMATE ASSESSMENT	2019 FHWA PILOT: ASSET MANAGEMENT	2018 DEERFIELD WATERSHED PILOT	2018 SHMCAP	2015 FHWA PILOT: CENTRAL ARTERY
FEMA 100-year Flood Plain	2012	Historical	This source provides The National Flood Hazard Layer (NFHL) dataset, which represents the current effective flood risk data for those parts of the country where maps have been modernized by FEMA.		X				X	
North American Regional Climate Change Assessment Program (NARCCAP)	2012	Both	This source provides the NARCCAP dataset, which contains high-resolution climate change scenario simulation output from multiple regional climate models (RCM) nested within multiple atmosphere-ocean general circulation models (AOGCM) for 30-year current and future periods. NARCCAP data are based on CMIP3. Nine of the NARCCAP GCM-RCM model outputs were included to support the Deerfield Watershed Pilot.					X		
NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP)	2012	Both	This source provides a dataset, which includes downscaled projections from the 21 models and scenarios for which daily scenarios were produced and distributed under CMIP5. The purpose of these datasets is to provide a set of global, high-resolution, bias-corrected climate change projections that can be used to evaluate climate change impacts on processes that are sensitive to finer-scale climate gradients and the effects of local topography on climate conditions.					X		
NCAR Community Climate System Model (CCSM4) downloaded from the National Center for Atmospheric Research (NCAR) Climate Inspector	2011	Both	This source provides an interactive web application that enables visualization and download of climate simulations by the NCAR Community Climate System Model (CCSM4) prepared for the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).					X		

DATA SET	YEAR PUBLISHED OR UPDATED	HISTORIC, FUTURE, BOTH	BRIEF DESCRIPTION	2024 FLOOD RISK ASSESSMENT	2023 RESILIENTMASS PLAN	2022 MA CLIMATE ASSESSMENT	2019 FHWA PILOT: ASSET MANAGEMENT	2018 DEERFIELD WATERSHED PILOT	2018 SHMCAP	2015 FHWA PILOT: CENTRAL ARTERY
High Snow Areas; Northeast States Consortium	2010	Historical	As part of a study funded by the FEMA Hazard Mitigation Grant Program, the Northeast States Emergency Consortium developed regional hazard maps for snowfall for the Northeast in 2010. Using their GIS data, a map was created to show which areas experience high snow levels, defined as greater than five inches, with a given frequency.		X					
MassGIS Data: FEMA Q3 Flood Zones from Paper FIRMS	2007	Historical	This source provides a subset of the data available on the FIRM map, from FEMA. All counties, except Franklin, are available for Massachusetts.		X					

Appendix 2. Resiliency Approach Summary Table

MassDOT Highway Division's approach to resiliency has five components which build upon State and Federal regulations, past accomplishments and actions, vulnerability assessments and interagency coordination: Plan, Improve, Maintain, Respond and Inform. This approach and related actions are summarized in the following table and defined in detail in the Resilience Improvement Plan **Section 4.** Action items from 2018 SHMCAP and the 2023 SHMCAP update: ResilientMass Plan are indicated with .

RESILIENCY APPROACH	COMPLETED ACTIONS	ON-GOING / IN-PROGRESS ACTIONS‡	FUTURE ACTIONS‡
PLAN Prepare for changing conditions and extreme events through vulnerability assessments and identify criteria to evaluate transportation asset vulnerabilities.	Massachusetts Coastal Flood Risk Model Deerfield Watershed Stream Crossing Resilience Pilot Project Stream and river crossing vulnerability assessment Implemented several recommendations from the Commission on the Future of Transportation Flood Risk Assessment for Highway District One	• Massachusetts Statewide Hydraulic Modeling Project Capture institutional knowledge through MOVIT (GeoDOT) Partnering with MassWildlife to incorporate habitat and fisheries considerations into MassDOT assessments, projects and planning	Develop resiliency screening parameters based on vulnerability assessments and best practices • Develop resiliency framework for MassDOT Metropolitan Highway System, including operated tunnels and underpasses • Integrate freight system assets into resilience plans
IMPROVE Incorporate resilience measures into projects and initiate resiliency-focused projects.	Supported development of the Massachusetts Climate Resilience Design Standards Tool Integrated climate resilience into capital planning activities and State Transportation Improvement Program (STIP) process Updated MAPIT to screen and score for environmental, social equity and health effect • Updated project initiation scoresheet screening criteria and scoring with climate resilience questions Updated Environmental Review Checklist (ERC) to include climate resilience questions Established Rivers & Roads training program Updated Bridge Design Manual to ensure projects consider future changes in hydrologic conditions	• Use MassDOT's Highway Division Project Scoresheet for project initiation and prioritization Complete the MassDOT ERC prior to scoping of a project • Complete the RMAT Tool for projects that are required to go through MEPA environmental review	Enhance resiliency screening in project development • Build out internal organizational structure to support implementation of the RIP Identify opportunities to track climate resilience and/or reduce vulnerabilities in project development Expand internal and external training for Rivers & Roads program
MAINTAIN Reduce disruption from extreme weather and changing conditions to existing assets over their service life through maintenance planning and coordination.	• Considered extreme weather and resilience in the lifecycle cost and risk management analyses in the 2023 TAMP	• Work with districts on maintenance plan and geospatial tracking of assets/ vulnerabilities • Bridge inspection program • Fund and implement the Programmatic Operations and Maintenance Plan (POMP)	• Conduct comprehensive culvert mapping • Implement culvert inspection program • Conduct comprehensive drainage inventory mapping • Establish extreme weather and maintenance working group
RESPOND Build and maintain capabilities to respond to and quickly recover from disruptions due to extreme weather and changing conditions.	• Coordinated with local, State and Federal partners on Cape Cod Emergency Traffic Plan (CCEPT) • Developed Critical Transportation Need (CTN) Evacuation Operations Annex as part of the Massachusetts Comprehensive Emergency Management Plan	• Maintain readiness to respond with multiple transportation modes as primary State agency for Massachusetts Emergency Support Function 1: Transportation Annex • Regularly participate in "all hazards" emergency planning and training with local, State, Federal and other parties • Maintain readiness to respond to and reduce disruptions due to extreme weather and changing conditions • Monitor weather forecasts	Integrate findings from vulnerability assessments into emergency management and operations response plans • Coordinate with other divisions within MassDOT on opportunities for disaster assessments
INFORM Coordinate resilience approach and actions with ResilientMass, municipalities, municipal planning organizations, and the public.	• Participated in the development of the 2018 Statewide Hazard Mitigation and Climate Adaptation Plan, and the 2023 update, dubbed the ResilientMass Plan.	Coordinate with State and Federal partners on resilience initiatives and regulations Encourage sustainable and resilient transportation through permit granting authority • Communicate known MassDOT highway vulnerabilities and resilience actions • Engage in collaborative resilience building with State, regional and municipal partners	• Coordinate with MVP Program to identify priority transportation projects • Integrate MPO risk assessments into the RIP • Update RIP to reflect results from ongoing and future actions

‡ *Implementation of actions pending funding*

Appendix 3. Priority Resilience Project List as of June 2024

MassDOT is investing in resilience through the Capital Investment Plan (CIP), State Transportation Improvement Program (STIP) and Statewide Long Range Transportation Plan (SLRTP). MassDOT is committed to integrating resiliency into existing projects and advancing stand-alone resiliency projects.

The priority resiliency project list included as this appendix to the Resilience Improvement Plan (RIP) was developed with MassDOT's District offices and focuses on known vulnerabilities, particularly those related to drainage, flooding, erosion and past extreme weather events. Areas of known vulnerability were identified in the 2023 Transportation Asset Management Plan (TAMP) as part of documenting MassDOT's progress toward a long-term SOGR for pavement and bridge assets, as shown in Figure A4.1.

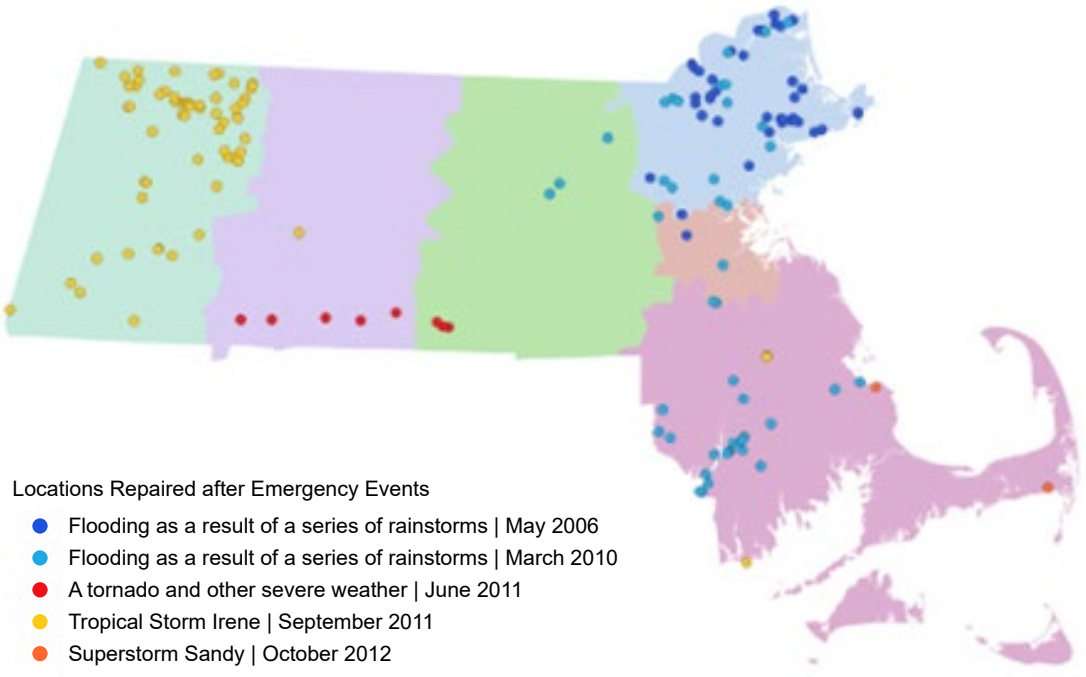
Locations Repaired after Emergency Events
Flooding as a result of a series of rainstorms | May 2006
Flooding as a result of a series of rainstorms | March 2010
A tornado and other severe weather | June 2011
Tropical Storm Irene | September 2011
Superstorm Sandy | October 2012

Figure A4.1: Locations cited for State or Federal disaster reimbursement (1997-2021).
(Source: 2023 TAMP.)

The known vulnerabilities identified through this effort were used as the foundation of the project priority list. The list is not comprehensive of all resilience projects for MassDOT, and is intended to grow as MassDOT continues to holistically identify resiliency projects through efforts described in **Section 4** of the RIP, informed by vulnerability assessments described in **Section 3** of the RIP. MassDOT will coordinate with the FHWA to update the list of resilience priority projects as they are identified through the project development process and pending results of completed risk assessments.

PROJECT NUMBER	LOCATION	DISTRICT	PROJECT DESCRIPTION	PURPOSE AND NEED	PROJECT SCOPE
609506	Becket	1	Ledge Removal along Route 8, Between MM 28.002 and MM 27.998	Improve safety of roadway users and establish a catchment area to mitigate geohazards within this segment of roadway. **Hazard(s) addressed: Landslide & mudflows**	Removal of eroded rock faces that have been crumbling onto the roadway by cutting into the rocks and establishing a catchment area to prevent rock deposit onto the road.
613025	Otis	1	Reconstruction of Route 23, including culvert replacement, O-05-004, Route 23 over Benton Brook	Prevent flooding and overtopping of the roadway and replacement of a deteriorating culvert structure. **Hazard(s) addressed: Flooding from precipitation**	The two existing, four-foot corrugated pipes are severely deteriorated. These pipes will be replaced with a new structure that will meet stream crossing standards and wildlife accommodations. Reconstructing substantial retaining walls may be required on the approaches to accommodate potential widening.
613159	Stockbridge	1	Culvert Replacement on Route 7 over Kampoosa Brook	Replace an undersized culvert that will provide improved hydraulic flow within the Kampoosa Bog. **Hazard(s) addressed: Flooding from precipitation**	The scope consists of assessing the hydraulic connection between the eastern and western wetland complexes and replacing the culvert to meet stream crossing standards to the maximum extent practicable.
613147	Bernardston	2	Ledge Removal for Highway Safety at Various Locations	There are locations along I-91 that have potential geohazards, such as rockslides. This project will improve roadway safety by removing those hazards. **Hazard(s) addressed: Landslide & mudflows**	To improve safety of users on I-91, the catchment area for rockslides will be enlarged to capture any debris coming from the slope.
613100	Petersham	2	Culvert Replacement on New Salem Road over Unnamed Brook	The purpose of the project is to replace two culverts under Route 122 (New Salem Road). One of the culverts is a 8x5 concrete box that is 70-feet-long and the other is a 32-inch concrete sound culvert pipe. This replacement will improve safety during major storm events, as well as replace a structurally deficient culvert where the side embankment is failing. **Hazard(s) addressed: Flooding from precipitation**	The scope of work is to replace the culverts to meet the stream crossing standards to the maximum extent practicable. At the 8x5 concrete box culvert, there will be a full replacement of the structure. At the 36-inch culvert, the scope is to replace the existing structure and widen it to provide wildlife accommodation within the Harvard Pond's ecosystem.
613104	Southwick	2	Culvert Replacement on Route 202 over Pearl Brook	Through a culvert inspection program, this location was identified as a vulnerable culvert based on stream morphology. The purpose of the project is to replace this culvert to prevent overtopping of the roadway during major storm events and blowout of the structure. **Hazard(s) addressed: Flooding from precipitation**	The scope of the project is to replace the culvert with a structure that will meet the stream crossing standards to the maximum extent practicable and provide improvement for stream crossing.

PROJECT NUMBER	LOCATION	DISTRICT	PROJECT DESCRIPTION	PURPOSE AND NEED	PROJECT SCOPE
613563	Deerfield	2	Culvert Replacement on Route 10 by Intersection of Wapping Road and Route 10	The purpose of the project is to replace an undersized culvert. Route 10 floods periodically and the replacement of this culvert will allow floodwater to pass through. **Hazard(s) addressed: Flooding from precipitation**	The scope of the project will include upsizing and replacing a deteriorated culvert to reduce flooding of the roadway during storm events. Additionally, the project will include a sidewalk to accommodate pedestrians and improve connectivity.
613573	Palmer	2	Culvert Replacements at Multiple Locations along Route 20 and Route 32	The project will improve safety by replacing structurally deficient culverts within Palmer, Massachusetts. Due to their size and conditions, these culvert locations have experienced flooding during storm events. This project will also increase safety by preventing further erosion of side slopes that would potentially undermine the roadway and cause sinkholes. **Hazard(s) addressed: Flooding from precipitation; landslide & mudflows**	The project's scope is to replace structurally deficient culverts that have caused flooding during heavy storm events. In addition, slope stabilization will also be part of the project to repair the erosions that have been happening because of poor drainage in the area.
612608‡	Worcester	3	Flood Relief on Route 20, Grafton Street (Route 122) Interchange to Flint Pond	The project will provide flood relief to the area. The area has been experiencing flooding for decades, which will shut down Route 20 for hours depending on the severity. **Hazard(s) addressed: Flooding from precipitation**	The proposed project will involve doubling the existing capacity of the drainage system along the Route 20 corridor to alleviate flooding issues. Work will include upgrading the current inlet structures and piping from the interchange of Route 20 and Grafton St (Route 122) to Flint Pond, a total of approximately one mile.
607904	Framingham	3	Culvert Replacement on Route 126 (Hollis Street) over Waushakum Pond Brook	The purpose of the project is to replace a deteriorating corrugated metal pipe. **Hazard(s) addressed: Flooding from precipitation; landslide & mudflows**	The primary need for this project is to replace the existing 36-inch circular corrugated metal pipe that had been damaged. Design will also look to move headwalls outside the clear zone and construct a guardrail to improve safety. The paved travelway dimensions are to match existing conditions. Sufficient space will be allotted for future improved pedestrian and bicycle accommodations under a separate project.

‡ *This project has received funding through the PROTECT discretionary grant program as of April 2024.*

PROJECT NUMBER	LOCATION	DISTRICT	PROJECT DESCRIPTION	PURPOSE AND NEED	PROJECT SCOPE
613162	Littleton	3	Culvert Replacement on Route 119 over Beaver Brook and Causeway Improvement for Wildlife	The purpose of this project is to improve a section of Route 119 over Beaver Brook in Littleton, Massachusetts. The causeway is at-grade with the surrounding wetlands and the Beaver Brook wetland crossing structure is undersized and deteriorating. The goals of this project are to reduce wildlife vehicle collisions, maintain landscape connectivity, flood resiliency and improve public safety. **Hazard(s) addressed: Flooding from precipitation; landslide & mudflows**	The scope of work will be to assess the hydraulic connection of Beaver Brook under Route 119 in Littleton. This will include replacing the existing culvert and design-construction of a properly-sized wetland crossing structure that meets the stream crossing standards to the maximum extent practicable. In addition, geotechnical evaluation will be required to determine the appropriate causeway improvements. Retaining walls or a similar design will be required to minimize wetland fill, serving as a barrier to keep wildlife off the roadway and direct them to the stream crossing.
613092	Haverhill	4	Two Culvert Replacements on Amesbury Road (Route 110) over Unnamed Tributary of East Meadow River	The project goal is to replace two culverts under Amesbury Road (Route 110) that have been causing flooding on the roadway. This replacement will improve safety during major storm events. District 4 has maintenance issues with the two identified culverts. The culvert by Turner Avenue has had more significant issues throughout the years, consisting of slope erosion, headwall failure and overtopping. **Hazard(s) addressed: Flooding from precipitation; landslide & mudflows**	The project scope is to replace two culverts that are failing and have caused Route 110 to flood during storm events. Additionally, the project will replace guardrails and improve drainage in the area to better prevent future flooding.

PROJECT NUMBER	LOCATION	DISTRICT	PROJECT DESCRIPTION	PURPOSE AND NEED	PROJECT SCOPE
606352	Wareham	5	Culvert and Dam Replacement at Mill Pond on Route 28	The project is to replace Mill Pond Dam, W-06-020(8M1), in Wareham, Massachusetts. The existing dam consists of five major elements: a fishway, primary spillway, secondary spillway, outlet pipe and the earthen embankment. The dam is found to be in poor condition, with significant growth of large trees throughout, apparent seepage along the downstream toe, bulging and/or rotation of the downstream stone masonry walls, apparent settlement of the upstream retaining wall at the auxiliary spillway, and other areas of possible movement and leakage. MassDOT proposes to reconstruct the dam to address several deficiencies. **Hazard(s) addressed: Flooding from precipitation; landslide & mudflows; coastal flooding and sea level rise**	The project scope will include replacing the existing substandard primary and secondary spillways with a reinforced concrete arched sharp-crested weir spillway located upstream of the existing secondary spillway location; constructing a new single-span steel stringer and concrete deck slab bridge to carry Route 6/28 westbound over the new primary spillway outlet; constructing a new concrete and stone masonry step pool fish ladder, with the upstream inlet located near the proposed east bridge abutment and the downstream outlet at the southwest end of the dam to feed into the Agawam River; abandoning or otherwise disabling the existing fish ladder and fishway to prevent fish from entering; and reconstructing the existing historic fishway to maintain flow as required. Additional scope items include demolition of the existing wood-framed storage shed that currently spans the primary spillway outlet channel and constructing a new wood-framed structure of approximately equal size at another location on the project site; clearing and grubbing the dam and dike embankments; installing rip rap protection along the upstream slopes; and reconstructing the existing roadway and sidewalks within the project limits that extend to the intersection of Sandwich Road (Route 6) to the west and Old Glen Charlie Road to the east.
612976	Oak Bluffs	5	Roadway Improvements and Culvert Replacement, Beach Road at Farm Pond	The purpose and need of this project are to address the lack of adequate tidal flushing of Farm Pond due to the existing undersized culvert, improve resiliency for the State highway on Martha's Vineyard that overtops in significant storm events, improve the crossing for non-motorized traffic at the existing crosswalk, and review the gap between the end of the sidewalk and beginning of the shared use path. **Hazard(s) addressed: Coastal flooding and sea level rise; hurricanes and tropical cyclones**	The work will include culvert replacement at Beach Road and Farm Pond inlet, raising the profile of the roadway and improving connectivity for non-motorized traffic.

PROJECT NUMBER	LOCATION	DISTRICT	PROJECT DESCRIPTION	PURPOSE AND NEED	PROJECT SCOPE
613156	Barnstable	5	Culvert Replacement on Route 6A over Boat Cove Creek	The purpose of the project is to replace a deteriorating culvert on Route 6A. This waterway is also a mapped herring run. By replacing this culvert, there will be better connectivity for the herring, as well as an additional tidal flushing in the inland area. This project will also evaluate the potential resiliency of the inland area by using Route 6A as a potential berm. **Hazard(s) addressed: Coastal flooding and sea level rise; hurricanes and tropical cyclones**	The scope of the project will include upsizing and replacing a deteriorated culvert that will help improve the herring run, as well as raise the profile of the roadway to prevent coastal flooding to the area.
613154	Wellesley	6	Drainage Improvements along Route 9 and Culvert Replacement for Flood Mitigation	The project's needs are to improve drainage and replace two culverts, which will alleviate flooding for Route 9 from Lexington Road to Ottaway Circle in Wellesley, Massachusetts. **Hazard(s) addressed: Flooding from precipitation**	The scope of the project includes drainage work to minimize flooding in the area and replace two culverts, one under Route 9 and another under the Cochituate Aqueduct.
613099	Boston	6	Slope Stabilization on I-93	Portions of the slopes supporting I-93 in the Dorchester neighborhood of Boston are beginning to slip due to ongoing erosion. In some areas, these slips have caused the roadway to settle, crack or begin to slough towards the falling slopes. These portions of the I-93 area are also at risk of damage from severe weather events given their location adjacent to the Neponet River and Dorchester Bay. Any severe weather event could accelerate slope collapse and cause significant damage to the facility. **Hazard(s) addressed: Flooding from precipitation; landslide and mudflows**	This project would add fill to extend the slopes supporting I-93 within the state highway layout where feasible, adding rip rap or other stabilizing materials, where necessary. Drainage improvements will be part of the project. In some locations, new retaining walls will be needed due to limited available right of way.